"Towards an Earth-Moon Economy – Developing Off-Planet Resources"

Moon Miners' Manifesto

www.MMM-MoonMinersManifesto.com

MMM Classic Themes — Research & Development

A start of a Litany of Research Needs

- Living Underground, with Sunlight and views
- Small market ariety in made-on-Luna goods
- Growing plants during day/night cycle
- Make locally, import: the MUS/cle strategy
- Robot-insect assistants for many tasks
- Ways to store dayspan power for nightspan use
- Liquid airlock systems for small cargo items
- Designing cities with their own biospheres
- Husbanding scarce water reserves
- Redesigning industrial systems to recycle water
- Harvest precious solar wind volatiles
- Music with instruments made on Moon
- Sports fun to play & watch in lunar gravity
- Experimenting glass-glass composites
- wastewater drainage recycling systems
- Biosphere / "modular" biosphere systems
- Probes for subsurface voids – lavatubes
- Designing better space suits/airlocks
- Extending the limits of teleoperation
- Positive uses for water under treatment
- Unique lunar surface vehicles•

Some Industrialization vectors

Beneficiating "poor lunar ores"
Glass-glass Composites
Colors in paints, ceramic glazes, glass etc.
Taking Silicone down paths not trodden
Electricl systems and superconductivity
Sintered Iron Products
Glass, Ceramics, Concrete
import packaging our of needed elements
Experimenting with Sulfur composites
Lighting systems – light without the heat

Many things need to be pre-developed if the first humans to return to the Moon are igoing to be the first of many, some of whom will choose to stay and create a new frontier. We also look into ways to get some of this research done early, so that once we do return to the Moon, we are not scratching our heads for what to do next for another few decades. Involving entrepreneurs to pre-develop those tcchnologies that have promising profitable terrestrial applications – here and now for those profits, is one way: the "spin-up" process. The University of Luna Project, which would coordinate research done in industrial labs as well as on university campuses is another. Without an intensive effort, we'll be stuck with another Antarctica.

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MMM #232 Lunar Base Preconstruction
MMM #234 Lunar Basalt Research
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Technologies for getting us to the Moon more efficiently

MMM #4 Bootstrap Rockets
MMM #198 The Outpost Trap: Transportation Systems:

Research for Lunar Vehicles

MMM #79 Vehicle Design Constraints;
MMM #84 Rural Luna. Surface Vehicles & Transportation; Over the Road long Distance Trucking; Toadmobile Conversions; The Skimmer; The Spider; Camping Under the Stars

Technologies for Exploring the Moon

MMM #45 Robo-Ants
MMM #130 Radar Flashbulbs on the Moon: Lunar Lavatube Locator Program
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Research in Operating in a Vaccum

MMM #132 Liquid Airlocks
MMM #142 Deadman's Spacesuit Thruster Pack
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Research in Building and Construction on the Moon

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MMM #5 Lunar Architecture
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MMM #18 Strategy For Following Up Lunar Soil-Processing With Industrial M.U.S./c.l.e.
MMM #60 Xities Beyond the Cradle: Unadressed Challenges
MMM #63 Lunar Industrialization - Cons, and Pros, of a Planned Lunar Economy
Beneficiation: making rich ores our of poor ores, Sintered Iron, Lunar Alloys.
Glass-Glass Composites, Glass, Ceramics, Color stuffs
MMM #198 The Outpost Trap: Modular Outpost Architecture and Construction;Teleoperation
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Research in Best Use of Lunar Resources

MMM #4 Paper Chase
MMM #23 Gas Scavenger
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MMM #38 Regolith Primage for trapped gasses. LUnar National Agricultural eXperiment Corp.
MMM #65 The Substitution Game, Silicone Alchemy, Sulfur-based Construction Materials, Fiberglass-Sulfur Composites; Fast Road to Lunar Industrial Muscle and the Substitution Game; Stowaway Imports.
MMM #67 Demo or Die;
MMM #154 Nitrogen and the Moon's Future

MMM #199 The Outpost Trap; ISRU Resource Utilization: Industrial Diversification Enablers
MMM #234 Lunar Basalt Research

Research for Utilities; Power & Water

MMM #66 Lunar Utilities; Superconductivity on the Moon; Wiring on the Moon; Light Delivery Systems;
The Phone Company; Encyclobin
MMM 67 Hydrogen as Industrial Grease; Hydro-Luna; Water reservoirs; The Settlement Water Company; Xeropcerossing
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MMM #136 Nightspan Lighting; Sulfur Lamps & Light Pipes

Research in Maintaining Lunar Biospheres

MMM #2 Moon Garden
MMM #40 Cloacal vs. Tri-treme Plumbing
MMM #49 Biosphere II, and III and IB and
MMM #64 Towards Biosphere Mark III
MMM #201 Modular Biospherics: Living Walls Systems;
Use of Lunar Lavatubes in a Lunar Analog Research Station Program
MMM #202 Modular Biospherics: Middoor Public Spaces added vegetation and wildlife
MMM #204 Modular Biospherics: Toilet-equipped Habitat & Activity Modules
MMM #207 Modular Biospherics: Tri-treme Plumbing

Research that supports "Good Living"

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Technology Research Locations

MMM #109 Role of the Settlement College/University
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Research & Private Enterprise

MMM #2 Moon Garden
MMM #3 Moon Mall, Moon Music
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MMM #65 The Substitution Game, Silicone Alchemy, Sulfur-based Construction Materials, Fiberglass-Sulfur Composites; Fast Road to Lunar Industrial Muscle and the Substitution Game; Stowaway Imports.

MMM #66 Lunar Utilities; Superconductivity on the Moon; Wiring on the Moon; Light Delivery Systems; The Phone Company; Encyclobin

MMM #67 Hydro-Luna; Water reservoirs; The Settlement Water Company; Xero-processing

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MMM #199 The Outpost Trap; ISRU Resource Utilization: Industrial Diversification Enablers MMM #201 Modular Biospherics: Living Walls Systems

MMM #202 Modular Biospherics: Middoor Public Spaces added vegetation and wildlife

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Lunar Software & Hardware Research & Development

NOTE: Some of the articles below are reprinted here only partially, that is, focusing on the portions of the article that highlight the need for further research and experimentation.

The paragraphs especially relevant have a light gray background, as does this sentence.

MMM #1 - December 1986

“M” is for “Mole”

In the pre-Apollo years, many of us grew up with images of what life would be like on the Moon and elsewhere from various science-fiction stories. One in particular, “The Moon is a Harsh Mistress” by the legendary Robert A. Heinlein, had painted a picture of lunar towns set in a maze of underground tunnels.

In the spring of 1985, the editor went to see a marvelous place called "TerraLuxe" [“Earth Light”] in the Holy Hill area about twenty miles northwest of Milwaukee.

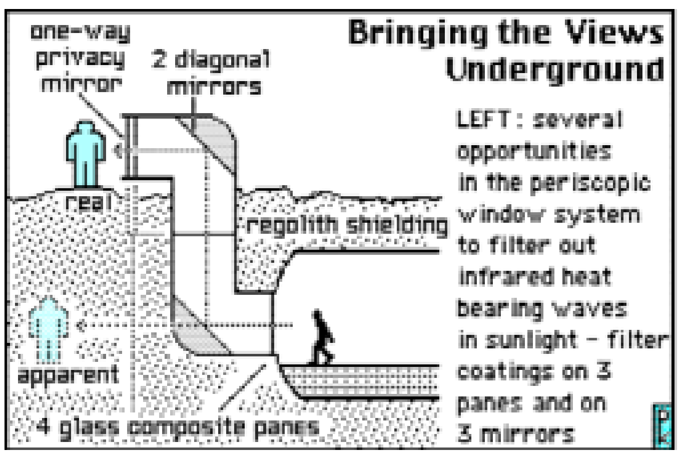
Here, architect-builder Gerald Keller (fittingly, German for "cellar") had built a most unusual earth-sheltered or underground home.

Run-of-the-mill underground homes are covered by earth above and to the west, the north, and the east, while being open and exposed to the sun along the south through a long window wall. But Mr. Keller's large 8,000 sq. ft. home was totally underground except for the north-facing garage door.

Yet the house was absolutely awash in sunlight, more so than any conventional above-ground house I had ever seen. Sunlight poured in through yard wide circular shafts spaced periodically through main room ceilings. These shafts were tiled with one-inch wide mirror strips. Above on the surface, an angled cowl, also mirrored on the inside, followed the sun across the sky from sunup to sundown at the bidding of a computer program named "George" (undoubtedly of "let-George-do-it" fame).

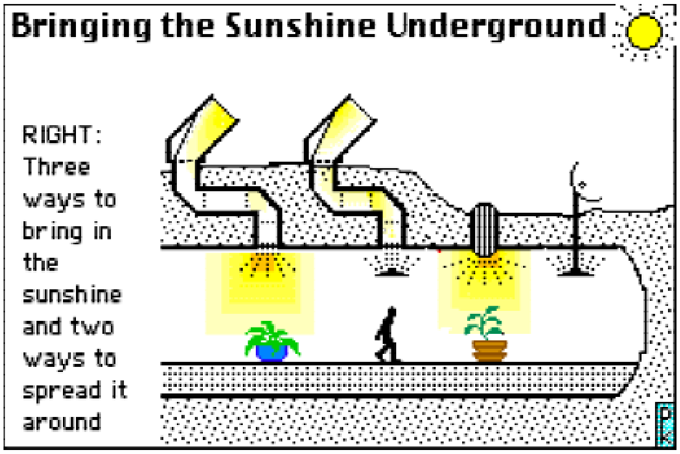
And, even more amazingly, through an ingenious application of the periscope principle on a picture window scale, in every direction you could look straight ahead out onto the surrounding countryside, even though you were eight feet underground. I felt far less shut in than in my Milwaukee bungalow!

This made an enormous impression on me. Heinlein was wrong. We could take the sunlight and the views "down below" with us. Our moon-dust-covered homes could be like Terra-Lux.



RESEARCH: Now **the "Z-View" periscopic window assembly** looks simple in principle. With the zigzag light-path, radiation protection is preserved. The interior air-pressure could be stepped down gradually, by one or two transparent panes, placed at intervals.

But it is not enough to take the idea to the Moon. It won't happen until someone tries to engineer, and pressure test, a real working model that can be designed in modular fashion for ease of assembly and made to plug into habitat modules designed to take them. This would make a really neat engineering project on a college level. And there would probably be a market for such devices in our own terrestrial underground homes.



Now the sunlight tubes in the Terra Lux home, were straight shafts. We would need to design them in zigzag pattern for use on the Moon, so as to avoid a pathway for cosmic radiation into the living space. A straight path option that would work would be a solid optic fiber bundle.

Again, the principles seem easy The need is to pre-engineer these “sundows” so that they would work on the Moon. Again, we would want to design them to be easily assembled in modular fashion, and to easily plug into habitat modules prepared to take them. Again, if we just assume that NASA or even some commercial contractor working on the Moon would take the time to design and manufacture such special plug-in features, we are going to be let down.

If we want future Lunan pioneers to enjoy life on the Moon as we do here, we’ll take the time to pre-engineer these “sundows” and “Z-views.”

Photo of the exterior of Terra Lux taken twenty years later - The turning sun-facing cowls had been replaced by simple domes. The exterior window panes of three periscopic windows units are visible.

This article has been preserved online at: http://www.lunar-reclamation.org/mmm_1.htm

MMM #2 - February 1987

MOON GARDEN

Moon Garden By Peter Kokh

[First of a series of articles on the need to predevelop the software of Lunar Civilization]

[First of a series of articles on the need to predevelop the software of Lunar Civilization]

Yes, the air and water of a Lunar settlement can be chemically recycled; and yes, the settlers can be fed synthetic foods so that it would not be strictly necessary to bring to the Moon any representatives of other living Earth species, plant or animal. However, most of us, would hardly find this conducive to morale on a lifetime basis. A settlement of colonists chosen for their indifference to the "real thing" could hardly be called "human."

Whether we think of it or not, human beings cannot be divorced from the rest of Earth life amongst which we have evolved not only biologically and physiologically but culturally as well. True, many persons live in homes and apartments that seem almost antiseptic, but Nature is just outdoors. On the Moon there is no world of living nature just outdoors, and colonists will most certainly feel compelled to go overboard in compensating for the Lunar sterility and barrenness by living in homes (i.e. not mere modules) that are lush with greenery, vivid with floral color, and sonorous with bird song.

Now the Lunar dayspan-nightspan cycle is twenty-nine and a half times as long as our day-night cycle; this presents a problem for Lunar gardening. True, a solar power satellite at L1 or some other amply sized power unit (e.g. nuclear) might allow colonists to cycle light and darkness to their gardens on an artificial 24 hr schedule. True, colonists themselves will live and work on such a schedule and illuminate their homes accordingly. But on the one hand, it is foolish to assume that energy available will always allow such lavishly inefficient usage.

On the other hand, once the beachhead base and its modules are outgrown and the first genuine Lunar homes are built on-site from building components produced from the lunar regolith, it is likely that these homes will have some sort of atrium floor plan centered around a solarium-garden flooded with sunlight captured by a heliostat and channeled perhaps along an indirect shielded route. (Glass, but not quartz, filters out ultra-violet). In such a garden, probably a combination of decorative and fruit and vegetable varieties, natural lunar cycling will be the ideal, efficiently using available energy, and avoiding excess heat buildup. We're not ready.

Should NASA spend precious dollars needed elsewhere to pay some mercenary to develop Moon-hardy floral and vegetable varieties? NO! It is rather up to those of us who would go there or prepare the way for others to someday acculturate themselves to satisfying lunar living, to experiment at our own expense to discover the hardiest varieties now around vis-à-vis length of the day-night cycle and keep breeding them until we have a Burpees- Luna Catalogue full of Moon-hardy varieties to grace Lunar homes and provide Lunar settlers with the same feeling of being cradled by Mother Nature -- despite the stark and harsh Lunar "outlocks" -- that we at home have grown up with here on our bounteous Earth.

RESEARCH: Finding plants that will thrive on fourteen and three quarters dates of continuous sunshine will surely be a lot easier than finding those that can shutdown, if you will, for an equal period of darkness, with the least need for punctuation by sessions under grow lights. But the closer we approach the ideal of natural Lunar cycling, the more efficiently will the colony be able to use available energy, and the more autonomously would the gardens maintain themselves. All of this holds true of the Lunar farms that will raise the major crops and staples as well.

Ideal will be the crops that can germinate and sprout in the warm, moist darkness and then sprint to maturity during the two week period during which they will receive more than a month's worth of sunshine by Earth standards. Next in desirability will be crops that mature by the end of the second sun-flooded period."

The need for this research led to the Lunar Reclamation Society's 1989 MiSST (Milwaukee Space Studies Team) project. Later, in 1990, David Dunlop, Peter Kokh, and Mark Kaehny founded LUNAX (L**UN**ar **A**gricultural e**X**periment) Corp. in an effort to get high school Science and Ag-Science teachers to involve their students in interesting "Dark Hardiness Experiments," testing various plants to see how well they did with all the light they could use during the 2-week long lunar "dayspan" to be followed by various "light diets" during the equally long "nightspan," and still go on to produce an acceptable harvest. You can learn more about the LUNAX projects at:

Http://www.lunax.org which redirects to http://www.moonsociety.org/chapters/milwaukee/lunax.htm

For the complete text of this article, see MMM Classics #1, pp. 3-5 - a 31-page pdf file download from

www.moonsociety.org/publications/mmm_classics/

The LUNAX effort has been resumed in 2009 after some years in suspension

MMM #3 - March 1987

MOON MALL

[The second in a series of articles on the need to pre-develop the "software" for a Lunar Civilization]

By Peter Kokh < kokhmmm@aol.com >

I remember as a young man too many years ago [1955] my first time in Hudson Bay Company (yes, the original Canadian Trading Co.) department store in Calgary Alberta. How impressed I was by the great variety of goods imported from all over the British Commonwealth -- an abundance of choices unsuspected by the shopper in Milwaukee's Gimbel's or Schuster's of that era. Things are different now. Today's shopper in any mall in America is confronted with a bewildering variety of offerings from all over the world. No one is limited to the goods and services made in his own city or town. Indeed, to be so limited, even in a great world class city like Chicago, New York, or Montreal, would be quite a come down.

How will it be for the shopper in a lunar or Martian mall the first few decades? The settlements will be small, though growing, and "**upports**" from Earth's gravity well will be prohibitively expensive. Almost certainly and without exception, they will be restricted to items, and even to mere components of items, that are both indispensable on the new worlds and as yet impossible to manufacture locally. For everything else, the settlers must be willing to make do with local resources and materials as best they can. No one ever said pioneering would be easy. The frontier may be exciting, but like frontiers from time immemorial, it will of necessity have its rough edges.

Will this mean one style, one color only of dishes, for example? One model, one color only for radios, stereos, and television sets? Only one style and color of sofa or chair or dresser? Uniform-like sameness in clothing? Unless we do some resourceful and ingenious planning now the answer might well be yes; and the consumers' paradise of Earth will have no counterpart in the consumers' pits on the Moon and Mars. There will simply be too few people to make more than the simplest variety of goods with no supplemental selection available through the Sears or any other mail order catalog.

Two approaches to this problem suggest themselves: one high tech, one low. For a small factory, changing styles, colors, shapes, etc. of whatever it makes in order to satisfy a variety of tastes usually involves expensive dies, molds, etc., and extensive downtime for setup changes. The challenge here is to design production equipment which is set-up friendly so that limited runs can be made on a dial-a-style or insert-a-card basis with little loss in efficiency. Some modern production facilities on Earth are already being designed in the fashion. I am not privileged to work at one. In this way, just as one can dial a pretty pattern by the turn of a kaleidoscope, a consumer could order a unique set of dishes, for example, or a unique bolt of fabric. At the least, small production runs in each of many styles could be made without extra expense. Without this commitment to design Lunar or Martian factories to produce such kaleidoscopic product lines, life on the new worlds will be very drab.

Remember, the people back on Earth won't care, and governments will give it bottommost priority. It's up to us to see that such possibilities come to realization.

The second approach which might work well on some lines of goods or be available as an alternative choice to the Lunar or Martian consumer is for the factory to produce (either exclusively or in addition to a regular line) a line of unfinished goods -- ready for the consumer or venturesome craftsmen to custom finish for him/herself or for resale. Some examples might be ready-to-glaze ceramic ware, ready-to-upholster furniture frames, and electronics chases sold without cabinets or with unfinished cabinetry, ready to dye, print, or otherwise embellish plain fabric bolts. Such secondary or co-manufacturing or custom craft finishing will likely become an important part of the frontier economy. And the person with crafting skills who can take a common ho-hum product and give it a unique and interesting touch might well enjoy the highest local prestige and social status. Those who do not have -- or refuse to develop -- the talent to custom finish purchased raw goods or who lack the income to pay someone else to put such touches on what they buy, might well be condemned to a home filled with the dull, boring, and commonplace.

Lunar and Martian society will greatly reflect this totally new set of rules in the consumer sport of acquiring a satisfying and personality-expressing collection of goods. On the Moon and Mars will dawn the new golden age of the artisan and craftsman. A "designer" item on these new worlds will mean something quite different from on Earth, for it will signify not a mass produced edition of a product designed by a famous name with high snob appeal, but rather a line of unfinished goods which have been designed to be easily, satisfyingly, interestingly, and kaleidoscopically finishable. And so there will be designer mediums, designer palettes, and designer frames and chases, etc. The designer who leaves the most scope for unique finishability will have the most honor.

Prospective settlers may be screened and accepted or rejected not only on the basis of their primary skill and occupation or profession but also on the basis of what they can contribute by their secondary talents, skills, hobbies, and avocations. If the new settlements are to avoid terminal blahs, the population will have to have a very high talent density in comparison with Earth.

We have already pointed out what we must seek to guarantee in the design of production
equipment shipped to the Moon or Mars. We must also seek to guarantee a high priority for artistic and craft talent amongst the selection criteria for prospective settlers.

But we can make their lot far easier by doing some experimenting beforehand to develop new means of artistic expression limited to the materials and elements commonplace to the new worlds. Lead, gold, silver, copper, etc., are vanishingly present on the Moon, for example. Thus ceramics cannot use glazes based on the lead oxides; certain kinds of stained glass will not be producible; new forms of jewelry will have to be developed; new stains, and paints, and enamels formulated. Pre-clayed soils will be unavailable for ceramics and water will have to be worked into utterly dry Lunar soils to make fireable clay, etc. If those of use who are into arts and crafts here on Earth take Lunar restrictions as a starting point and through lots of work develop workable new crafts, that will give the colonists a head start. Without such SOFTWARE predevelopment, any Lunar civilization founded on hardware alone will surely suffer a fatal morale collapse. Can you help?

R**RESEARCH:** Since this was written, computer aided manufacturing techniques have made this possible.

We can do much useful research, now, to design basic stock goods that are especially friendly to further customization by entrepreneurs and artists and craftsmen on the Moon, as the foundation of a healthy cottage industry movement.

The above essay is online at: **http://www.asi.org/adb/06/09/03/02/003/moonmall.html**

♬ MOON MUSIC ♪

MOON MUSIC By Peter Kokh kokhmmm@aol.com

A few weeks ago I took in an unusual concert: the Northern Illinois University (De Kalb) Steel Drum Band, largest and oldest in the country, was playing at the UWM Union (University of Wisconsin - Milwaukee). I went to get a fore taste of "Moon Music."

Humor me a bit with these assumptions. Musical instruments will not be "upported" ("up" the gravity well) from Earth to the Moon base or settlement -- too expensive. Yet the personnel or settlers will surely want to enliven their "evenings" with more than prerecorded music. This means fashioning musical instruments out of lunar materials in the base or colony shops.

What can they do without wood, without drum skins, without brass (which is a copper alloy: the Apollos' limited prospecting would indicate copper is no more than a trace element on the Moon)? Not being a fashioner of musical instruments by trade or hobby, I honestly don't know. But definitely, one option is the West Indies' steel drum, a cut-off 55 gallon drum whose bottom is then beat with a set of sledge hammers into a complex concave shape capable of sounding from 3 to 36 full, round, vibrant notes. Certainly assorted bells and cymbals,"saws", xylophones, and even marimbas with metal, glass, or ceramic resonator tubes will work. Music has been played on a keyed set of drinking glasses. And to be sure the electric guitar with a ceramic, composite or metal body.

But stringed instruments with wooden sound boxes or brass wind instruments? No way! Can something passable or even special in the way of stringed sound boxes and wind instruments or horns be made from such lunar materials as glass, glass composite, ceramics, steel, aluminum, etc.? Why don't you musically gifted tinkerers out there see what you can come up with. But indeed just the instruments above will make a great orchestra!

The NIU band includes an ensemble of thirty steel drums -- each tuned differently to complement each other in orchestral fashion. No amplification needed! While the band's repertoire includes the usual calypso, pan, and reggae tunes, it amply demonstrated the great versatility of these instruments by such numbers as Cool and the Gang's "Cherish", Dionne Warwick's "That's what friends are for", Bizet's "Carmen Overture", and the opening movement of Bach's "3rd Brandenburg Concerto." Unbelievable and very moving. The steel drum shows all the dominant lead power of the piano and yet can be as soft and delicate as the violin.

I doubt Moon settlers will ever miss Earth's traditional orchestral instruments. They will do quite well with what they can make from Lunar resources. The results will help contribute to a unique Lunar culture with a flavor all its own. Recordings of lunar renditions and original Lunar compositions will take their place on the shelves of Earth's music stores. Some Earth FM stations may even feature lunar music just as others feature soul, rock, jazz, classical, pop, and country. Some Earth groups may even catch the fever and "**downport**" instruments made on the Moon.

RESEARCH: Wouldn't it be fun for our chapter to have a small "Lunar Ensemble" to play at our various public events? A steel drum or two, a xylophone, a marimba, some bells, cymbals, and castanets? Perhaps you know someone who isn't all that interested in man's future in space but would find it fun to be associated with us in this way. Working with associated groups like this would be one way for us to extend our influence beyond our core of dedicated activists. Sleep on it. **MMM**

The above essay is online at: **www.asi.org/adb/06/09/03/02/003/moonmusic.html**

MMM #4 - April 1987

BOOTSTRAP ROCKETS

By Peter Kokh

But then the hypocrisy about favoring settlement of the Inner Solar System should stop. Such an engine, discussed by A. H. Cutler (in Aluminum Fueled Space Engines to Enhance Space Transportation System Effectiveness, Springboard to the 21st Century, NASA / ASEE Summer Study, 1984, by A. H. Cutler) and alluded to by Gimarc will not serve as the bootstrap rocket needed by a Lunar Colony to support itself without wholesale handouts from Earth. Getting to the Moon only counts if we do so in a manner that allows us to stay there and thrive no matter what non-supportive political-economic decisions are made on Earth. To this end only an engine that burns Moon-sourced fuels exclusively will do. With such an engine, the Earth to Moon freight bill would reduce itself (so far as bottom-line balance of payments are concerned) to no more than the Earth to LEO (low Earth orbit) cost. The Moon could pick up cargo and settlers in LEO and transport them the rest of the way essentially free.

[The above was written more than a decade before Lunar Prospector's confirmation of substantial water-ice reserves at both lunar poles. Since that discovery, many have called for using this resource to produce liquid hydrogen and liquid oxygen rocket fuels. This would constitute a one time non-recyclable squandering of a limited resource that took hundreds of millions of years to be deposited. The "rocket jocks" who couldn't care less about lunar settlement and only want to jet set around the solar system on voyages of discovery, can scratch their itch elsewhere. The writer stands adamantly opposed to the production of rocket fuels from lunar polar ices when they are not necessary. Once we are this far out on the shoulder of Earth's gravity well, hydrogen-free fuel combinations with a lower Isp produced locally on the Moon will do quite well. -- PK.]

The aluminum rocket IS the answer, of course, but without the costly Isp enhancing hydrogen purchased from Earth sources. Burning powdered Lunar aluminum with liquid Lunar oxygen, O2 (possibly enriched with ozone, O3), in a hybrid engine will not have the high Isp performance we have grown used to, but it will be superior to the CO/O2 fuel system now being favorably considered for Mars based operations.

[Other metallic fuels worth investigating are iron, especially as powdered unoxidized iron is abundant in the surface regolith and needs only a magnet to harvest. - PK]

Whatever problems there are in development of a working Al/O2 engine pale into insignificance in comparison to the rewards. Apparent “obstacles” will not discourage those with the right stuff, or can-do mind-set.

Meanwhile, the H2/Al/O2 rocket is but an expensive distraction that wins the battle of orbital transfer operations but loses the war of space settlement. It must be resisted. MMM

R**RESEARCH:** Note: prototype rocket engines burning both powdered aluminum and powdered iron have been tested, and perform reasonably well. While they do not have the performance of LH2 and LO2 burning engines, they should work well enough for craft plying between say the Lagrange point 1 and the lunar surface some 60,000 miles away.

But this technology is not ready to use. We need to develop Al-Ox and/or Fe-OX burning engines of the size needed singly or in multiples for the L1-Lunar Surface runs. This will be a less expensive option they should be attractive to commercial rocket companies.

Burning hydrogen harvested from shadowed polar craters instead of reserving it for tightly closed-cycle operations in industry and for the settlement biospheres would amount to high treason with regard to our dreams.   MMM

PAPER CHASE

PAPER CHASE II By Peter Kokh

[Third in a series of articles on the need to pre-develop the SOFTWARE of a Lunar Civilization]

By Peter Kokh kokhmmm@aol.com

On Earth with its vast atmosphere, oceans, and still extensive forests, we can arguably afford to withdraw such organic ingredients as hydrogen and carbon from the environmental cycle in the form of paper, plastics, etc. After all, Nature has been doing the same thing, "banking" these elements for geologically long times as coal, oil, and gas.

On the Moon the situation is quite different. Hydrogen and carbon do exist in amounts worth scavenging in the upper layers of Lunar soil, put there by the incessant solar wind. From Apollo samples we might expect every thou-sand tons of soil processed to yield (besides over 400 tons of oxygen) one ton of hydrogen, 230 lbs. of carbon, and even 164 lbs. of nitrogen (source: Stuart Ross Taylor. Planetary Science: A Lunar Perspective. Lunar and Planetary Institute, 1992, p 159). This is hardly abundance. Polar permashade fields certainly must be searched, but this scenario requires that the Moon's axis will not have shifted more than a degree or so in the past 3.5 billion years: a tall order. If any ices of water or carbon oxides are found there, they will certainly be needed to expand the biomass of the colony. Withdrawal and banking will still be quite out of the question. Hydrogen and carbon for non-biological uses will still be priced as "import elements."

[The above was written in 1987, eleven years before Lunar Prospector confirmed the existence of ice deposits at both poles. Yet the caution remains. Even billions of tons of hydrogen, carbon, and nitrogen (presuming that the ice contains carbon and nitrogen oxide ices as well, which one might expect if the source is comet impacts) -- even so much is not enough to support (a) lunar biosphere(s) if the population on the Moon grows to a considerable size. A conservative approach is still the best strategy, if we are not to stunt the growth of lunar development. -Ed.]

Paper is basically cellulose, a carbohydrate, half hydrogen & carbon, half oxygen. Its production in modern forms is very taxing on environmental air and water. While this may be a justifiable tradeoff on the bounteous Earth, the toxic burden of its production would soon overwhelm the very limited environments of Lunar (or in-space) settlements even if "waste papers" were recycled 100% (which would necessitate brainwashing all would-be settlers.) Luna City (and "New Tucson" at L5 as well) must be a paperless society. Throwaway addicts will argue this, of course, but then addiction has always been resistant to treatment.

[SNIP: Section on books and magazines (we predicted the Kindle reader!, boxes, labels, etc.]

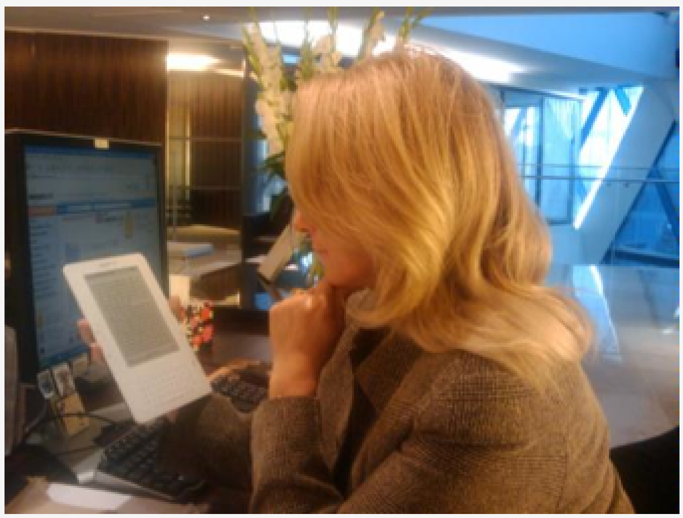
Now a paperless society, Lunar or L5, is an enormous challenge and we had better begin preparing for it. A whole spectrum of alternatives must be developed and ready-to-go to address the diversified applications of paper in our civilization that have so insinuated themselves into our way of life as to almost define it.

Greeting cards and love notes: One can foresee a non-commercial and unpoliceable use of homemade art papers (such as are now well represented in art fairs) and vegetable inks for this purpose. Maybe the contradiction of personal mass produced greeting cards will at last give way to something that really does show individual effort. A possible black market item.

In this article, we suggested various ways to substitute for, or make do without, the various uses of paper, which as an organic material made largely of hydrogen, carbon, and oxygen, only the latter being abundant on the Moon, would be rather expensive. We will need to conserve all the hydrogen, carbon, and nitrogen we can harvest from solar wind gas particles in the moondust, or from yet-to-be quantified and qualified polar shadowed crater “icefields” for biosphere and agricultural uses only.

RESEARCH: In this article, written in the Spring of 1987, we called for the invention of an electronic book and magazine reader. “Electronic books, magazines, and newspapers, etc. to be inserted into the reader must be quite compact especially if hydrocarbon plastics are involved so that the weight ratio to paper replaced is as high as possible. All metal alloy and/or silicon would be the best. Downloading from central library/databases may well fill much of the need.”

Happily, in 2008, Amazon.com introduced the Kindle™ which neatly took care of this needed technology development item; and all because there was a market for this sort of thing here on Earth.



This is a perfect example of “Spin-up” research as opposed to “Spin-off.”

For the complete text of this article, see MMM Classics #1, pp. 11-12 pdf file download from www.moonsociety.org/publications/mmm_classics/

For information about Kindle™ see: http://www.amazon.com/gp/product/B0015T963C/ref=sv_kinh_0

MMM #5 - May 1987

LUNARARCHITECTURE

Lunar Architecture By Peter Kokh

[Fourth in a series of articles on the need to pre-develop the "Software" for a Lunar Civilization]

Through the years, a variety of suggestions have been made for the erection of the First Lunar Base. Most common is to make use of fully prefabricated shelters (such as space station modules or re-outfitted space shuttle external tank) imported from Earth and / or a low-Earth orbit (LEO) space station and burying these in the Lunar soil. A less expensive method of erecting a base of similar limited scope is Dr. Lowell Wood's plan (of Project Columbus) to use inflatable kevlar (carbon fabric) bags (air pressure would be more than enough both to inflate them and to support the overburden of protective soil).

Construction techniques may seem to be a HARDWARE question. But what is built on the Moon will depend _entirely_ on the philosophy behind our presence there. Without the right SOFTWARE of purpose, nothing significant will happen.

The stated purpose of most lunar base proposals seems shortsighted: to serve as a base for doing Lunar Science (Selenology, but the lazier term Lunar Geology is in vogue) and for mining engineers tending a largely automated operation. A word about Lunar Science. Few laymen perhaps have as high a "selenology curiosity quotient" as the writer, but science is properly the function of a living community already in place. Many would-be Lunar Scientists want only to titillate their own curiosity and then go home.

But our purpose has to be different: to make the Moon a second human world. Science in the long run -- much, much more of it -- will follow naturally, science done not by visitors from Earth but by people who have adopted the Moon as their new home.

The type of small prefabricated initial base described above makes better sense as a construction shack for a much larger facility to be built with as high a percentage of native Lunar materials as is initially possible. T. D. Lin's proposed 90,000 square ft, three level, 210 ft diameter concrete structure might be ideal (see the sketches on the last page of MMM #3) in which 55 tons of terrestrial hydrogen is called for in comparison to 250 tons of Lunar steel, 1500 tons of Lunar highland cement, over 10,000 tons of Lunar soil used as aggregate, and over a million tons of soil used as shielding. [see illustration on page 8]]

If expansion is to be an afterthought, it will end up being a forgotten dream. Such a truly Lunar base might be large enough to support open-ended goals of developing non-token Lunar agriculture, pilot materials processing industries, and production-scale 100% Lunar sourced building materials and construction / erection equipment and methods. If (expansion is to be an afterthought, it will end up being a forgotten dream (and you can carve that quote in marble). The only base it is worth building on the Moon is one whose function it is to prepare the methods and tools needed to expand into a full blown settlement.

Only if we make it possible for several thousands (not dozens) of people to live on the Moon from generation to generation (not just through short tours of duty) can we:

(1) develop a Lunar economy that is truly full and autonomous

(2) develop a genuinely Lunar human culture and civilization to express and unfold potentialities hidden in humanity since the dawn of time ("Be all that you can be")

(3) say truly, that the human presence on the Moon is more than that caricature we find in Antarctica and that we have securely established humanity beyond Earth. Only then will we begin to cut the umbilical cord that ties us to the womb world.

So Lunar Architecture, or “LunArchitecture”, must be a charter function of a bona fide base. Considerations flowing from the goal make several things clear.

1. Speed of “labor-light” construction is essential.

To begin with, "Lunarchitects" must develop a system that can provide shelter at a pace sufficient to house settlers as fast as the growing Lunar market / trade / economy can absorb them. This means that not even lip service can be given to the time-honored slow, labor intensive housing construction methods. What is important is to build secure shelter as simply and quickly as possible -- let us be so bold as to aim at one per day per crew!

There is a place for labor-intensive, artful, craft-rich, proud work, and that is in the leisurely discretionary finishing of interiors. This can be do-it-yourself or contracted on a pay-as-you-go basis, etc. and can be stretched out over years or even generations. We'll thus employ the analogs of brickmasons and carpenters for interiors, but they have no place in erecting the pressure shells of Lunar indoor / “middoor” spaces.

2. The “Dirt Cheap” Goal

The pressure shells of buildings must be literally dirt-cheap. One cannot "live off the land" nor "sleep under the stars" on the Moon. The place for flaunting affluence is in interior finishing. To keep the basic construction "regolith-cheap" two things are necessary: extrusion of the shelter from the site itself and the use of the least amount of construction energy necessary to do the job well.

3. The Concept of the Lunar "Great Home"

The "right to ample living space" ought to be “religiously” pursued, nonammendably, nonpostponably. Add-on space will be difficult, risky, and expensive. All the pressurized shell-volume that oeven an extended family might want should be provided at the outset. Young families might make a "cozy place" in only a part of this and slowly grow into the rest. Included should be solarium and garden space large enough to provide a respectable fraction of their food needs and to help to keep their air fresh as well as provide an oasis of serenity and delight. Another bonus of this "right to ample space" approach would be the availability of in-home areas for starting entrepreneurial cottage industries.

It is necessary then to purge the mind of the facile but inappropriate examples of the prefabricated space station habitat module. Even if manufactured on the Moon, they would be more energy intensive in their construction and almost guarantee a stiflingly stingy allotment of sardine space in turn for the ever unfulfilled promise of more spacious quarters "when the settlement can afford it."

A limited amount of technological homework has already been done along lines that would enable the realization of the goals just outlined. We already know that the Lunar soil can be compacted and then sinter-fused with a mobile magnetron, a high-power microwave generator (the idea of Tom Meeks of the University of Tennessee). This would be ideal for road surfaces, floors, and exterior walls set into excavations in the soil. We know that the soil can be melted into cast-basalt slabs ideal for interior partitions and roof segments, with the balance of the excavated soil being replaced on top as shielding while the interior is being pressurized. We know how to build safe periscopic Lunar picture windows (see MMM #1) and heliostats to flood the interior with sunshine.

But much work needs to be done. Using imported epoxy resins as sealers would be prohibitive. At the least, the natural glass-like glazing of the cast and sintered surfaces may well reduce the need for sealant to joints. In the temperature stable Lunar underground environment with no vibration to worry about from wind or occasional mini moonquakes, and no water-table-induced settling to worry about, this sealant may not need to be as flexible as one might think. Perhaps glaze patching would do the job. On site experiments will be needed to prove out these ideas and build production-capacity equipment.

The scandal of totally unnecessary cost multipliers built into the present establishment approach has discouraged many, leading them to settle for the little dream, the token base, in the false hope that it is a foot in the door. We must not be sheepish about insisting on the Big Dream, our only chance! **MMM**

RESEARCH: We need more entrepreneurial reseach in “Hybrid-Rigid Inflatable” Architectures, qne in ways to securely connect modules in a leak proof way. This includes utility runs and connections, corridors, etc.

MMM #9 - October 1987

MOON SPORTS

Moon Sports

In this article, we looked at the very different conditions under which sports would need to be pursued on the Moon, even within pressurized spaces. While gravity (and traction) are reduced, only 1/6th our familiar Earth level, momentum (and impact forces) remain the same. Our familiar sports of football (American), baseball, basketball, soccer (football elsewhere) could be no more than caricatures if played on the Moon.

RESEARCH: Thus we need to leave those sports behind and, by computer simulations, invent new ones designed for lunar conditions of 1/6th gravity yet standard mass and momentum. Moreover, we must "design" sports that are fun to play and fun to watch. There might even be a television market on Earth for some lunar sports events!

For the complete text of this article, see MMM Classics #1, pp. 12-13 - a 31-page pdf file download from the source cited above.

MMM #16 - June 1988

GLASS GLASS COMPOSITES

GLASS-GLASS COMPOSITES By Peter Kokh

Glass-glass-composites, more exactly glass-fiber-glass-matrix-composites, are a new and promising material for construction and manufacture. This new bird in the flock of materials available to man is still inside the eggshell but pecking away at it. What we know of GGC's promise we owe to Dr. Brandt Goldsworthy of Goldsworthy Labs in San Francisco, who at the request of Space Studies Institute (SSI) in Princeton, New Jersey, made laboratory-sized samples and then investigated their properties. His work gives reason to believe that GGC building materials will be as strong as steel or stronger, and considerably less costly in energy terms to manufacture.

The occasion for this bit of incubation of a theoretical hunch lies in careful analysis by SSI of the possibilities of producing serviceable metal alloys from the common ingredients in lunar soil. While the Moon is rich in iron -- some of it free uncombined fines -- and other important metallic elements such as aluminum, titanium, magnesium, and manganese, these are just starting points; to make alloys with good working properties, other ingredients in lesser amounts must be added. It turns out that our customary and familiar stable of alloys used on Earth often require recipe ingredients that are not easily or economically isolated from the soil. Furthermore, alloy production takes a great deal of energy and therefore represents a technology direction for a very advanced lunar civilization, and not one for an early base trying to justify its existence with useful exports to LEO or elsewhere.

Alloys will come on line someday; it will take "Young Turk" metallurgists without defeatist attitudes ready to scrap Earth-customary alloy formulations and experiment from scratch with available elements until they have a lunar-appropriate repertoire that will serve well. But that is another story. Here we want to explore the tremendous potential of GGCs.

A "Spin-Up" Enterprise Plan

RESEARCH: But how can we explore the potential of a laboratory curiosity? We can't. Are we to wait until we get to the Moon and then fiddle around, hoping that we come up with something before the base has its next budget review? You would think so from the present dearth of activity.

Why not haul GGC out of the lab and put it through its paces in the real world? Sure that takes money, but with a little imagination it is easy to see that GGC could become a profitable industry, here and now, on good old Cradle Earth. And if so, our newly acquired expertise and experience will be ready to go whenever the powers that be establish a long-term human foothold on Luna.

What is the realistic market potential that would justify the effort and expense of getting off our bottoms and pre-developing this promising technology now? If we are talking about something only useful for industrial construction material, the threshold for successful market penetration is high. Our GGC products must come on-line either cheaper than every competing material or have such superior properties as compared to existing alternatives as to force potential customers to take the gamble. But to limit ourselves, especially at the outset, to such a line of products is not only accepting unnecessary barriers to success, it shows a great lack of imagination.

Does GGC have a potential for consumer products? This is an important question, for with such products cost can be secondary to other considerations such as visual appeal due to inherent special design and style possibilities, etc. The consumer market could be a much easier nut to crack, and once established and experienced there, our infant industry would be better poised for market entry in the industrial- commercial world.

Before we speculate further, we must take a look at this intriguing new material and put it through the paces to see what we can and can't do with it. Without that, we are building castles in the air.

RESEARCH: Can we get the matrix glass to melt at a sufficiently low temperature by doping it with sulfur or phosphorous, both reasonably abundant on the Moon, rather than with lead, which is scarce on the Moon. The melting point with sulfur or phosphorous is higher, but may be practical.

We have a logical plan of attack for these experiments thanks to the analogy of GGC to a long familiar family of materials with which we have abundant experience: fiberglass reinforced plastic resin composites, the stuff of which we make boat hulls, shower stalls, pick-up toppers, whirlpool spas, corrugated porch roofing, and a host of other handy products. Fiber reinforced plastics or FRPs offer the game GGC entrepreneur a handy agenda for exploring the talents of the new material.

First our enterprising hero will want to see what fiberglass-like fabrication methods GGC is amenable to mimicking. Can (or should) the still hot and workable glass matrix with glass fibers already embedded be draped over a mold to take its form, or be compression molded in a die and press? Can (or should) the glass fiber be set in the mold and then impregnated with the molten glass matrix? (The magic of GGC lies in using two glass formulations: one with a higher melting point from which to make glass fibers, and one with a much lower melting point to serve as the matrix in which the reinforcing fibers are embedded.) Can (or should) the glass fibers be first impregnated with a cold frit of the powdered glass that will form the matrix upon heating in the mold to its fusing point? Once the entrepreneur has learned which fabrication methods work best or can be adapted to the idiosyncrasies of GGC in various test formulations, he is ready for the next round of experimentation.

Fabricating a "piece" of GGC with a certain useful size and shape is only the first victory. We must learn how to machine it: can the material be sawed, drilled, routed, tapped, deburred, etc.? We need to know this before we can design assembly methods. If adhesives are to be used, what works best? Thermal expansion properties of GGC formulation will be important, as well. Once our entrepreneur has done all his hands-on homework, knows what he can do with this new stuff, and has outfitted his starter plant with the appropriate machinery, tooling, and other appropriate equipment, it's time to sit down with his market-knowledgeable partner and decide on product lines.

RESEARCH: But let's back up a moment. We said we were going for the consumer market as the ideal place to get our feet wet, and for this market one thing is paramount: **visual appeal.** So we go back to the lab and start playing around with our formulations. Glass of course is easily colored. Coloring the matrix glass will not provide us with a distinctive product. But colored glass fibers in a transparent glass matrix suggest tantalizing possibilities. The fibers could lie in random directions, be crosshatched or woven, swirled, or combed to give an apparent grain. We will want to see which of these suggestions are most practical, which have the most stunning and distinguished consumer eye-appeal, etc., all without compromising the strength of our material. As to the colors: black, green, brown, blue, cranberry, and amber would give us an ample starter palette. But before buying up binfulls of the needed ingredients we could do some inexpensive footwork, using abundant and inexpensive green and brown bottle glass for our fibers to give us a first feel for likely results of this avenue of product enhancement. Our homework done, we're ready to burst onto the world scene.

Computer visualization of the possibilities:

Our recycled long-empty plant (the rent is cheap and a lease wasn't necessary) has been humming for a while now. Production hasn't begun because the designers are still working on the molds and dies for the introductory product line. Buyers and outlets are being lined up. At last Lunar Dawn Furniture Company is ready to greet the unsuspecting world.

RESEARCH: At first we produce only (stunning of course) case goods: coffee and end tables, etageres and book cases and bedroom sets, etc. Then we introduce a line of tubular patio furniture that makes the PVC kind look gauche. Next we branch into an upholstered line with beautiful external frames. Office furniture, striking unbreakable fluted glass lamp shades, stair and balcony railings, and unique entry doors are our next targets.

Our prices are somewhat high at first, at least with the initial lines, but we were the rage at the fall furniture show in North Carolina and the spring Home Shows in every town. Lunar Dawn takes it's place beside Early American, Mediterranean, Danish Modern, and Eighteenth Century English.

We introduce less expensive but still appealing lines and franchise our operations, targeting especially the less developed nations that need to curtail their forest razing and which have an abundance of the raw materials needed for glass making. But we also begin to diversify into the commercial and industrial markets. We've learned to make beams and panels and now offer a whole line of architectural systems for competition with steel and aluminum pole buildings, etc. One of our branches is now marketing GGC conduit and pipe at competitive prices. Another branch is offering a full range of clear non-laminated safety glass for buildings and vehicles.

Meanwhile, we are not resting on our laurels in the consumer world. Casings for small appliances, cookware, ovenware, and table ware; handles, wash basins, and countertops; boat hulls for boulder-studded white water use; all are now available in GGC. A big hit with the fans is our indestructible flag-ship in the sports world, our GGC bodied Demo Derby Dragon. The same car has won its first dozen events and looks none the worse for it.

Of course, we've long since abandoned the cumbersome GGC or Glass-Glass-Composite tags. The public got what it needs, a simple one syllable pigeonhole. We're known and recognized everywhere as GLAX, a word that suggests glass with a difference: strength. And visually, the "ss"-replacing-"x" even suggests the dual composition involved.

You'll see in the logo symbol an allusion the Moon. For the ulterior motive inspiring the people behind the successful Glax entry into Earth markets was the need to predevelop a technology suited for early lunar bases and settlements.

Glax will provide a relatively inexpensive, uncomplicated industry for the settlers both to furnish badly needed exports, and just as important, a whole range of domestic products that will help hold the line on imports. As such, Glax is an essential keystone in the plan to achieve economic viability and autonomy for the projected City. There is a lot of enthusiasm on Earth now, not just for a lunar scientific outpost à la Antarctica, but for a genuine settlement.

This change of attitude did not happen by accident, and the story of Glax on Earth played a major role in this turn of events. Glax, since the first door-opening day of Lunar Dawn Furniture Company, was aggressively marketed as an anticipatory lunar technology. The public began to get the idea that moon dust might be good for something and that the idea of a self-supporting settlement relying largely on its own resources was not a flake notion, but rather something reasonable, even to be expected! Lunar Dawn helped th process along when after moving into its brand new plant in suburban Milwaukee, it built a simulated lunar home next door, soil-sheltered and all, with solar access, periscopic picture windows, ceramic, glass, and metal interior surfaces, and of course furnished with its own Glax furniture lines. The habitat was accessed by "pressurized walkway" from the meeting hall display room-library-computer network room and gift shop built alongside and used free of charge by Milwaukee Lunar Reclamation Society.

How did this all happen? Notice the fine print on Lunar Dawn ads and billboards (also used in connection with other Glax product companies): it reads "An Ulterior Ventures Company." Ulterior Ventures isn't some big conglomerate but a unique venture fund which the National Space Society helped to organize to give entrepreneurs willing to predevelop anticipated lunar technologies for Earth markets, a little help to get started. Successful members of the Ulterior Ventures family pay a royalty that helps build the fund for even more ambitious exploits. In future articles we hope to tell you about other successful -- if not so well known -- members of the Ulterior Ventures family. Future Fact or Science Fiction?

Fiction? Yes. An unrestrained flight of fancy? No! This is the sort of thing that could happen with NSS encouragement, if the society can be persuaded to show the same enthusiasm for direct action as it always has for indirect agitation "to make it happen." Having to start from scratch to build the infrastructure to incubate and support such "ulterior ventures" would mean an unwelcome setback in time, effort and personal energies.

RESEARCH: The brand new infant industry sketched above does not require expertise in preexisting sophisticated technologies to get started. Almost any of use could get in on the ground floor of such an endeavor in one or more capacities. Any takers? MMM

A Strategy For Following Up Lunar Soil-Processing With Industrial M.U.S./c.l.e.

By Peter Kokh

"M.U.S.-c.l.c." a 2-part Acronym

You will notice the unusual way we spell "muscle." Our strategy calls for the:

M.U.S. (Massive, Unitary, Simple) parts to be made by the settlement and the

c.l.e. (Complex, Lightweight, Electronic) components to be made on Earth to upport up the gravity well and be mating on the Moon (or early space colony).

Here then is the logical formula for giving industrial muscle to the early settlement still too small to diversify into a maze of subcontracting establishments. It is a path that has been trod before. It plays on the strengths of the lunar situation and relies on the early basic industries: lunacrete, iron-steel, ceramic, and glass-glass composites (glax). And not surprisingly, it is the path of lunar development that will produce the most in exports to LEO, GEO, L5 (?), and even Mars. MMM

RESEARCH: To make this idea work, we need to mount a mass effort at "**Lunar-Appropriate Industrial Design**" to redesign items needed on the Moon, so that the "cle" (complex, lightweight, electronic) components made on Earth, in subassemblies where practical, can be easily mated with MUS (Massive, Unitary, Simple) components and assemblies on the Moon. We should launch such a "**Lunar-Appropriate Industrial Design**" **Society or Institute**, to further these goals

How can a small settlement (anything less than some hundred of thousands and probably a whole lot smaller) have the most effect industrially? Some "muscle"? Fortunately, we have a clear and precise criterion by which to judge, and it points the way like a beacon: keeping upport tonnage from Earth to a minimum, i.e. making do for as much (mass-wise) of the settlement's needs as possible from local lunar resources. To strive in this direction, the settlement, while not neglecting any possibilities, will do well to give top priority to items which, multiplying unit weights by quantity needed, embody the greatest opportunity for savings if manufactured locally.

Among equally weighty categories, those items that require less industrial sophistication and diversification and which are not unreasonably labor intensive would naturally get first attention (e.g. one ton of dishes over one ton of electronics).

Shelter itself, with some parts of utility systems (e.g. pipe and conduit at least), and basic furniture and furnishings made of 'lunacrete', iron and steel, ceramics, glass, fiberglass, and glass-glass composites (glax) are obvious items on the list. Such things should account for most of the settlement's physical plant.

What about sophisticated products: machinery of all sorts, vehicles, electronics, appliances? Too ambitious? Only for the unreourceful! Consider that every supposedly more involved product is an assembly of parts that often includes a shell, casing, cabinet, body, hull, table, etc. that is less complex and yet often represents a considerable part of the total weight of the item. If such parts were made in the settlement and final assembly done there (the really complicated and sophisticated portions representing the output of ny subcontractors being preassembled on Earth in subassemblies as large and as integral as can be) this will hold down the primarily weight-determined upport price of everything from major shop tools to telephones to vehicles.

This would mean standardizing the size and interfaces of upported subassemblies, cartridges, chases, etc. to fit the very minimal number of cabinet, casing, and body models, etc. that the small lunar work force could produce. (If the completed item were upported, parts supply would be the only limiting factor on variety). Even so, "standard" cabinets and casings could be made to take varied finishes, textures, and colors.

Now the way we make many items on Earth, especially electronics, would lend itself to this approach. Of course, a central office (on Earth would save lunar manpower from paperwork) would have to coordinate everything, so that only chases and work-trays, etc. that would fit made-on-Luna casings and cabinets would be upported. This should not be hard to arrange on a bid basis.

The weight savings on major appliances in cases in which the settlement is not yet prepared to make more than the housing should be considerable. Many such items could be redesigned so all the sophisticated "works" are in one or a few slip-in cartridges.

This reasoning holds just as true if it turns out that the first off-Earth settlements are in free space colonies rather than on the lunar surface. Such settlers would operate under the same restrictions until their numbers are vast enough to support self-manufacture of all their needs.

They too will need the right strategy to build industrial "muscle." Why not vehicles (both surface and intra-biosphere) with the body or coach made on the Moon, designed for easy retrofit of a cartridge-like wiring harness, control panel / dash, and motor (even here major heavy parts could be locally made and designed for ease of final assembly)? The benefits of such a setup would be immense.

To maximize the possibilities for "lunar content" and the ease of final local assembly will require designing such vehicles from scratch with this very goal as utmost priority. In a future article, we will talk about the need for an agency to take the initiative in stockpiling such "cartridge designs" for future lunar need.

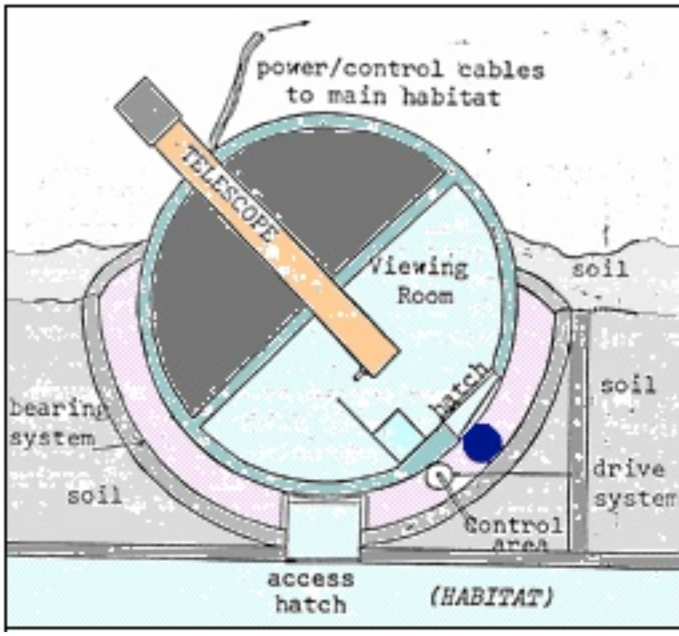
Keep in mind that lunar surface vehicles are vacuum-worthy spaceships. So the next step would be Earth-Moon, or rather LEO, low-Earth-orbit to Moon or lunar orbiting depot) ferries of high lunar content (cabin, hold, tankage, etc.) and then even space station modules for LEO and GEO designed for easy snap-in outfitting of "works" from Earth.

MMM #20 - November 1988

AMATEUR LUNAR TELESCOPE DESIGN

Wherever humans will go, some of them will want to look at the stars and planets. But on a world like the Moon, without an atmosphere (much less an unbreathable one), that poses some problems.

How do you design a telescope that one can use without donning a spacesuit? Looking through an eyepiece while wearing a helmet would simply not work. Of course, one can put a telescope on the surface and have the digital electronic feed go to a viewing screen in the comfortable home interior. But we ran a design contest for ideas on how to pursue amateur astronomy without using such electronic workarounds.



Amateur Telescope to be used on the Moon, without a spacesuit
Access to a spherical viewing room is via a hatch in the ceiling of pressurized habitat. Once inside, seated in the chair, the viewing room rotates in directions needed to aim the telescope on the desired target.

Looking through a space suit helmet just would not work! This design is from an MSOE (Milwaukee School of Engineering) student, Ron August, and was the winning entry in a design contest cosponsored by the (Milwaukee) Lunar Reclamation Society and the American Lunar Society in 1988-89.

How would you provide for stargazing in shirt sleeve comfort on the airless Moon?

Submitted by Milwaukee School of Engineering (MSOE) student and MLRS member Ron August of Hubertus, Wisconsin. This concept involves a moving, spherical shaped viewing room, with the telescope an integral part of it, that is completely pressurized, heated, and accessible from the habitat below by way of an airtight hatch system. Once inside the viewing room, the observer will be strapped into a viewing chair which has all controls for movement of the telescope (and viewing room) and focusing of the telescope. Movement of the telescope/ room is achieved by a controller wheel which moves the room into position to point the telescope at anything above the horizon in all directions. The room is suspended by a low friction smooth-running bearing system. **MMM**

MMM #23 - March 1989

GAS SCAVENGER

Waste-not, Want-not: Available Byproducts of Soil Moving

By Peter Kokh, based on these sources:

1 Lunar & Planetary Institute, Houston and Research School of Earth Sciences, Australian National Univ., Canberra. pp. 147-169.

2 "Water and Cheese from the Lunar Desert: Abundances and Accessibility of H, N, and C on the Moon" by Larry A. Haskin, Dept. of Earth and Planetary Sciences and McDonnell Center for the Space Sciences, Washington Un., St. Louis, MO.

The powder-like dust of the lunar surface is a housekeeping scourge. But this same fine grain texture carries with it a fringe benefit that more than makes up for any nuisance factor. It was one of the biggest surprises of the Apollo Moon

Rock studies to find that this pulverized soil had been acting like a sponge soaking up the solar wind for four thousand million years. While the lunar rocks and soils themselves are extremely dry and deficient in volatile elements (those which melt and vaporize at relatively low temperatures) there are plenty of these elements both adsorbed to fine grains and trapped in minute cavities and pockets within soil particles.

Particles from the solar wind, from solar flares, and from cosmic rays, each leave characteristic traces and from these it is clear that the solar wind has been the main source of the volatiles we now find. Other sources include volcanic fire fountains or fumaroles and meteoritic or cometary bombardment1. By all these means, the upper meters of the lunar surface has become effectively saturated. A lunar form of fossil sunshine if you will. **Travelers in the Wind**

Foremost of these guest elements is hydrogen – protons comprise 90% of the solar wind – followed by Helium – alpha particles comprising 10% of the solar wind1. While no hydrogen has yet been found in lunar rocks proper that gives any indication of being native and while no water or water-ice has yet been found [as of 3/'89, eight years before the Lunar Prospector mission], the amount of adsorbed hydrogen is far from negligible.

It is estimated that there is enough hydrogen in one cubic meter of lunar topsoil to yield, combined with lunar oxygen more than a pint and a half of water.

Extending this figure to the Moon at large, the total global regolith layer, if it could be harvested 100% for hydrogen, could yield a lake of water 10 km wide x 68 km long by 100 meters deep (roughly 6x40 miles by 330 ft. deep).2 While this is hardly an ocean full it is a surprising amount all the same. The real question is whether this endowment can be harvested economically.

Carbon and nitrogen, which are found as traces in the rock (30 and 1 parts per million respectively) are enriched in the regolith soil to 115 and 82 ppm (kg per thousand metric tons). 1 Another way of putting this is that an area mined 6m long x 6m wide and 1m deep contains as much nitrogen as an average human body. Or consider that the amount of carbon locked up in soil organisms on Earth is only 2.7 times the amount of carbon adsorbed to the same amount of moondust. It's just there in a totally different form than we are used to finding and harvesting it. We need new methods, new tools, a new way of living off the land.

In Earthside laboratories, gasses trapped in lunar soil samples have been released by simple heating. Some gasses will need more heating to scavenge, others less. Further pulverizing may be needed to release compressed gasses trapped in glass cavities and vugs (small, irregular-shaped, rough, crystal-walled cavities inside rocks) at pressures commonly as high as five thousand atmospheres!

Laboratory methods are one thing. Engineering the equipment to do the job economically on a large scale in routine fashion is another.

Here is a hardware R&D job as ultimately important as any.

While it may be true that extracting the H, C, and N in a finite amount of lunar soil could provide for all the needs of an appreciable biosphere2, the first milestone might well be the ability to make up for all leakage losses with the gasses extracted from the soil in the everyday 'lith-moving involved in building roads, excavating shelters, covering new habitats with shielding etc. As this would mean that all imported H, C, and N could go towards increasing the size of the biosphere, it would be a major step on the road to self-reliance.

What we are suggesting then is that any piece of regolith-moving equipment involved in constructing the various parts of the base/settlement-to-be or providing the various processing plants with ores should routinely process all the soil it handles to harvest the gasses trapped in the soil.

This capability should be built-in. On page twelve of this issue, there is a sketch by Pat Rawlings (Eagle Engineering) of a mobile soil harvester in the service of the liquid oxygen industry. This sketch appears in Ben Bova's 1988 book Welcome to Moonbase. In our view, such a machine should never be built as depicted.

Scavenging soil gasses (not including the oxygen chemically combined in soil minerals, at c. 45% by weight) must not be an afterthought, an accessory to be added later, a luxury to be built into future models.

Scavenging soil gasses will be an exercise in self-endowment and the settlement that does not practice it de rigueur will not deserve to succeed. Gasses harvested in excess of current need will become a capital investment in the settlement's future. A lunar community that practices such gas scavenging will have a friendlier more at-ease attitude to its adopted world than one which, not doing so, chooses by default to remain a stranger in a strange land.

It's hard to say what a proper gas scavenging soil mover would look like. A lot depends on whether or not it is practical to do at least a first sort of the different gasses into separate tanks on the spot, possibly attached to sequential heating chambers, or whether this task is best done in a fixed plant. If the gasses can be stored compressed, the soil mover can do more work before unloading full tanks and taking on empties. Is anyone working on such a gadgetmobile? We would be surprised.

The Noble Gases

As to the noble gasses (chemically inert, not reactive with other elements) each cubic meter of 'lith contains an average 20 grams of Helium, 2 each of Neon and Argon, 1 of Krypton, and a milligram of Xenon. The extent to which these gasses can be economically extracted from the soil may well determine which form of lighting bulbs and tubes it will be most imafeasible to manufacture on the Moon using the highest possible 'lunar content'.

Will neon lighting, presently undergoing a tremendous renaissance in this country, play a major role in illuminating as well as decorating lunar habitats? As soon as a settlement reaches a certain viable size it will pay for it to provide for its lighting needs by self-manufacture so this question is not an idle one.

The Implications

There are strong implications in all this for lunar city-planning. Contrary to the usual vision of lunar settlements in which personnel are limited to cramped quarters sardine-style, our future lunar sodbusters engaged in routine gas scavenging may find it profitable to construct more square footage of habitat and more footage of pressurized passages and roadways per person. As avoiding cabin fever will be harder than on Earth, this may be the only way to sustain general mental health and morale. Lower density living brings with it lessened vulnerability to impact damage, and a larger biosphere mass per inhabitant i.e. "MM Manifesto!" **MMM**

NOTE: This article will be followed by another, entitled “Primage,” on the same subject, below.

RESEARCH: Can we design and build gas-scavenging equipment to go on any moondust-moving- equipment? Dave Dietzler of St. Louis believe that the equipment needed to heat the soil to the necessary 600-700°C will be too heavy for any but dedicated units.

MMM #34 - April 1990

RECYCLING

RECYCLING By Peter Kokh

[This outline of materials-management systems appropriate for Space Frontier settlements. It also addresses some persistent Earth-side problems.]

Recycling is an integral and essential aspect of our "tenancy" of whatever corner of the universe we occupy. It is custodial common sense. And if it is becoming sound economics here on Earth, it will be an absolutely vital cornerstone of economics on the Space Frontier.

ORGANIC & SYNTHETIC MATERIALS

First we'll need to recycle organic and synthetic materials derived from such volatile elements as hydrogen, nitrogen, and carbon which will not exist in the all-surrounding abundance we are accustomed to on Earth, even after we are able to supplement the vanishingly meager lunar sources with supplies from volatile-rich asteroids and comets. This self-discipline will be indispensable for Lunar Settlement, and highly advised for Space Colonies in near-Earth space.

Keeping the ratio of native lunar vs. exotic imported content as low as possible will alone allow any chance for a favorable trade balance and economic self-reliance.

Thus priority must be given to our food and clothing needs in using these precious elements. The purpose of such an effort is to provide the lowest Cost of living, by stretching the service life of any volatiles imported at great expense and by reserving them for uses for which there are no substitutes.

INORGANIC MATERIALS

Contrary to intuitive expectations, it will also be salutary to recycle processed inorganic materials since they embody considerable energy expense already invested in extracting and processing them from raw regolith soils. The more energy intensive a refined material is, the more to be gained from recycling it. Proper pricing of virgin materials will guarantee this outcome.

Tailings also embody the energy investment of their by-production, and using them to make secondary building products would capitalize on this investment. [See "TAILINGS" MMM # 25 p. 5. May '89 - republished in MMM Classics #3]

Even glass cullet and ceramic shards can be used e.g. embedded in glass matrix decorative panels covers, fronts, handles and knobs. In the case of inorganic materials the purpose of all this effort will first be to reduce total energy-generation requirements, a strongly economic motive. Secondly, it will help settlers to minimize the Acreage of surrounding moonscape that will need to be disturbed to maintain there a popula-tion of a given size, an aesthetic goal. This "discipline" will allow us to tread softly and caringly on the magnificent desolation of an adopted virgin world.

Our strategy for realizing this authentic way of life will have many subtargets. Appropriate product design, easy sortability, convenience, collection nodes, routing and route servicing, divi-sion of responsibility, supply versus demand volume-matching, entrepreneurial opportunities, youth and school involve-ment, contests, public discipline, tax incentives, and backup systems must all be given special attention.

RECYCLING - FOUR BASIC PATHWAYS.

(1) REUSING of all refillable bottles and containers is the most obvious and most economic.

(2) RECASTING by crushing, shredding, melting, and then recasting fresh items is another. We do this with paper, aluminum, and plastics for example. This method is greatly hampered by unnecessary cross contamination with durably-bonded unlike materials. As for markets for recycled temporary-use items, building products and furnishings best match the supply.

(3) RETASKING or use-reassignment is a greatly underutilized third avenue. Timid examples are jelly jars designed for long reuse as drinking glasses and butter dishes designed to be reused as refrigerator ware. There have been at least three abortive efforts to design what has been termed a "world bottle", a glass beverage bottle ingeniously shaped to serve anew as a brick or building block. That is one task worth taking up afresh! Designing smaller high-fashion glass bottles for infrequently sold items, such as spices, fragrances, medicines, etc., with a female-threaded punt on the bottom to match the male-threaded neck would allow combining these into stylish decorator spindles for any number of imaginative uses. Formulating packaging and packing materials to serve as craftstuffs for artists or even as fertilizer for gardeners is a promising possibility. In any such dual purpose design effort, it will be critically important to find reassignment uses with adequate demand-potential to match, and use up, the full volume of supply. Otherwise any such efforts will be but futile and distracting gestures.

(4) REPAIRING is one avenue increasingly being abandoned because of high labor costs.

RESEARCH: Repair costs, however, could be greatly reduced by more careful product design with greatly increased attention to assembly sequences and methods that are take-apart-friendly.

The present quest for seamless sophistication in appearance is one of several sirens luring manufactures in just opposite direction.

To repairing, we add **refinishing and totally fresh makeover**. Even where repair or refurbishing is impractical, if the item in question cannot be economically disassembled, then the sundry parts that would need separately recycling will end up being irretrievably trashed.

RESEARCH: Only the adoption of design and manufacturing methods not now in favor will make all this viable. Lunar manufacturers will need to sing this new tune. And frontier settlements cannot in the long run afford to import Earth-made items not knockdown friendly.

The extra cost of meeting these new requirements will be minor in comparison with Earth to Moon up-the-deep-gravity well freight charges.

INSTITUTE FOR MOON-APPROPRIATE INDUSTRIAL DESIGN

No amount of recycling discipline on the part of our hardy pioneers will work without such a wholesale redesign of consumer goods. For this reason, we really do need to start now by establishing an Institute for Moon-appropriate Industrial Design. While aimed at meeting demanding frontier requirements, the very constructiveness of this challenge should make such an Institute the prestige Alma Mater of choice for industrial design students the world over, regardless of whether they had any intentions of ever leaving their comparatively soft Earth lives behind.

INDUSTRIAL ENTERPRISES

The significant upfront role of industrial enterprises in creation of a material culture in which much more extensive and thorough recycling is possible than in our current American experience, is not limited to proper product design. It should be the highest priority of Frontier Governments, to provide encouragement and incentives sufficient to ensure that the principal avenue of industrial diversification involve new enterprises wins the byproduct materials of those already in place. Again, this compounds the productivity of energy already spent.

Properly integrated industrial parks will involve suites of industries in an ecosystem of traded byproducts. In one highly successful entrepreneurial effort in Texas a few years ago, an enterprising computer buff went from plant to plant, asking for data an any unwanted supplies, scrap, and byproducts to put in his data bank. Within the first year, he was able to generate enough networking between sources of previously unadvertised supply and potential customers to take in a cool $5 million for himself.

RESEARCH: "With a good system, even those who do not care, will do the right thing. Without a good system, even those who do care, can’t do the right thing."

Given goods that can be separated, sorted, and economically recycled, the consuming citizen will at last have an honest chance to do his/her part. But it is not enough to know what should be done. Both citizens and government must also realize that without proper organization, on several levels, it won’t happen.

SORTING

"A place for everything and everything in its place" is an unbeatable philosophy for managing one's basement, attic, and closets. It also applies to the home and business recycling corners.

RESEARCH: Instantly identifiable bins or baskets must be conveniently arranged for every category to be sorted separately. There is no reason that home recycling centers have to look untidy, a hodgepodge of Rubber Maid baskets and paper bags. A top priority household product should be some sort of bin-susan or bin-rack setup. Why entrepreneurs aren't turning such things out here and now is beyond my comprehension.

On the Space Frontier we'll need a greater number of different bins than we do here, where our economy is only organ-ized to take in aluminum, paper, glass, and some plastics. Glass, glax*, ceramic shards, and the various metals; refill-lables and tradables, used cotton cloth, fiberglass fabrics, thermoplastics, paper stuffs, dye stuffs, plus various compost categories all need separate bins.

A collection system with convenient nodes to see that all these items find their way back to the industries that can use them, is the next equally critical and indispensable element in the recycling triangle. Perhaps the electric delivery vans of the settlement could belong not to individual merchants but to materials circulation enterprises. They would pick up appropriate categories of disowned goods even as they deliver, a prerequisite for a license.

ALTERNATIVES AND OPTIONS

But there must be many alternative routings to make a system work. If containers and packages in which shoppers bring things home are designed to collapse or nest compactly, they could be reused conveniently. It might even be bad taste to leave home empty handed! Drop-off Centers could be centered in each shopping center for convenience. Properly arranged and managed (a place for every-thing) they needn't be unsightly.

Featuring lockers, public toilets, cafes, they could include floral gardens, stalls for artists and craftsmen, repair and makeover shops etc. And why not arts & crafts classes, street music, dress-up fashion and bauble shows, and even a "soap box" for those eager to share concerns?

COTTAGE INDUSTRIES

"Scavenge and Trade" licenses could be given preferentially to those with cottage industries based on giving new life to cast-off materials and items. Art du Jour, serendipitous temporary sculptures made from collected items, could be a major draw. Such creations might feature those items and sort categories for which the supply exceeds demand in the hope of stimulating would-be entrepreneurs and artisans to discover fresh unsuspected possibilities in over-available stuffs. Demonstration classes in arts and crafts using recycled and discarded items would be in order. In Space Frontier pioneer towns, "recycling" may finally 'come out of the Alley"

Farm-Mart Centers, wherever grocery shopping is done, should not only take in the appropriate refillable containers but also buy/sell sundry categories of compost and composting accessories such as paper stuffs (e.g. corn husks) and garden and kitchen scrap dye stuffs, bone, and fat could be handled separately from any compost that exceeds home garden needs.

Jailed inmates could do the heavy duty labor intensive disassembly work; pardons might be in order for those demonstrating their capacity to function as useful citizens by entrepreneurial development of markets for orphaned and high surplus sort categories clogging the network. Primary and Secondary School involvement will be crucial in making the system work. This is the subject of the next article. [see "The 4th R" just below]

ROLE OF THE UNIVERSITY

Finally, the frontier University has a role to play as orchestra leader.

The University, not government bureaucracy, must assess how well the system is working, and develop needed improvements.

A University office would maintain the computerized current inventory of various depositories with a disciplined materials accounting system monitoring supply/demand imbalances, and circulation efficiency, assign identifying sortation logos and routings for new classes, and maintain updated guidelines on a utility cable channel (or website).

RESEARCH: The University should supervise and assist entrepreneurial experimentation in its labs and shops to develop new materials and products that will take advantage of various kinds of discard stuffs that are in excess supply. As such it will be a principal incubator of new businesses and economic diversification.

The University's Institute of Industrial Design would work to find new ways to implement such philosophies as "whole sheet" no-scrap design of product/accessory combos, "kosher" assembly of unlike materials for later ease of separate recycling, "honest surfacing" that utilizes the design advantage and character of materials undisguised by surface treatments that make proper sorting identification anything but easy.

VOLUME REDUCTION STRATEGIES

Not only must we provide for proper sorting and routing of items to be recycled, we must take care that the system is not overwhelmed. Volume reduction strategies are in order. In the USA, 40% of trash is packaging materials.

In MMM # 4 April '87 "PAPER CHASE" [page 4 - above] we pointed out that wood, paper, and plastics will be prohibitively expensive. This whole fascinating topic of how to service the diverse packaging, labeling, and even the advertising needs of the settlement with minimum reliance on precious volatile-rich materials, that need to be reserved to increase the mass of the biosphere "flywheel", will be the subject of a separate article in a later issue of MMM.

SUMMING UP:

We must not allow either Lunar or Space Settlements to be "born addicted" to a technology and culture of abundance and waste.

RESEARCH: All those elements needed to make this ambitious program work must be developed beforehand, pre-tested and pre-debugged before lunar settlement begins. It would be best if as much of L as is appropriate could even be ready to go for the first NASA/ International Moon Base.

Those of us interested in off-planet settlement must begin the cooperative addiction-treatment program that will enable such a propitious fresh start, as well as create spin-ups that will aid in Earth's own environmental struggles.

Beating this addiction, from which we all suffer, will require a "wartime" dedication and inventiveness. Only to the degree we succeed will we prove ourselves worthy citizens of Earth's con-solar hinterland. **MMM**

"The Environment" - whether on Earth or on the Moon it's a question of pay less now, or pay much more, later.

MMM #38 - September 1990

Concepts of Regolith Primage

PRIMAGE

A "Do or Die" Key to Lunar Industrial-Agricultural Success

By Peter Kokh

The pre-tilling of the Moon

Through eons of meteorite bombardment, lunar soils have been extensively "gardened" or turned over vertically, and even mixed horizontally – up to half the surface materials in any given area is the import of splash-out (impact ejecta) from areas nearby and distant alike. On Earth, mineral-based industries have been able to take advantage of enriched and concentrated deposits – a result of eons of geological processes peculiar to our planet. While undoubtedly somewhat more favorable concentrations of a few minerals do occur on the Moon (homogenization provided by bombardment not being 100% thorough), in general lunar settlers will have no choice but to make do with deposits we would shun as "uneconomic."

While the Moon is richly endowed, in a gross sense, the lunar economy will have the much more difficult job of separating out or beneficiating the desirable minerals prior to processing. No one should imagine that just any system of lunar mining-based economy would guarantee success. In "Gas Scavenger" [above, pp. 9-10] we pointed out that if we religiously extracted the pure iron fines and all the

Solar Wind deposited gases from any and all regolith that we had to move or handle anyway, we would then accumulate potentially valuable reserves, at low cost, that could be one principal means of diversifying the settlement economy. We have to move regolith in excavating for shelters, in covering them with shielding, in grading roadways, and in providing raw materials to ore processing facilities. Iron fine removal (by magnet) and gas extraction (by heat) capabilities should be an integral part of ALL regolith-moving equipment, we counseled.

Agricultural Needs

Let’s carry the argument further.

Apparently, some of the things that worry lunar agriculture researchers most are actually characteristics of 'gross' lunar regolith easily changed in the handling process. After all, settlers won't be erecting domes over undisturbed lunar regolith, and then attempt to farm this raw soil. We will be building pressurized agricultural modules of whatever volume – and then, moving regolith from the outside into the prepared beds within.

Researchers worry that the 15-20% fraction of regolith, which is ultra-fine powder of less than 0.25 mm grain size, fine to medium silt, will clog soil pores to waterlogged soil. In the Moon's light 'sixthweight', water will percolate through the soil more slowly; thus we will want somewhat coarser soil than is ideal on Earth. In the course of bringing regolith-soil in from the outside, this fine silt can be removed by vibration sieving or by 'winnowing'. As a bonus, this unwanted fine silt may have a higher content of adsorbed Solar Wind gases; also it may be easier to process in some ways (glass?, ceramics? etc.,) than less refined 'as-is' regolith.

The 75% ideal medium-sand-through coarse-silt 1.0-0.25 mm fraction is next. A 3rd sieve removes larger agglutinate glass nodules, which can then be transformed into zeolites by mild hydrothermal processing [150^o C, 0.3 MPa, 76 h]. Zeolites are hydrated silicates of aluminum with alkali metals (K, Na) and cavity-rich crystal lattice structure.

They can be used as catalysts, adsorption media for gas separation, insulation, and molecular sieves. And added back into the “soil”, they will enhance mineral ion transport to plant roots, especially in early 'immature' soils not yet fully colonized by microorganisms nor laden with organic matter. How to provide for sufficient mineral ion transport in regolith-derived soils is thus another needless worry on the part of researchers. [In view of these possibilities, I am rather critical of the value of lunar agriculture experiments that use any lunar simulants formulated on the unexamined presupposition that we will be stuck with using crude raw regolith.]

The remnant after this last sieving operation would be larger rocks (aggregates and breccias) that could serve well as gravel fill, for lunar concrete. So, just by including this multistep vibra-sieving operation in our "Regolith-mover", we will have (1) enormously enhanced the chances of success for lunar agriculture; (2-5) started businesses in molecular sieves, gas-separation, catalysts, and insulation; (6) supply the highly refined material needed for processing; and (7) supply coarser material for 'lunarcrete' mix. A third worry of the Lun-Ag people is potentially toxic levels of chromium and of nickel in regolith-derived soil.

Their concern is perhaps more justified with chromium, as observed nickel concentrations are possibly tolerable. How we could make use of regolith pre-handling opportunities to extract a significant fraction of the Chromium-containing minerals (e.g. some spinels) is a nice challenge for the chemical-engineering types among our readers. How about it?

A Tool for Many Needs

Now that's quite a workload for our everyday Lunar 'Lith-Mover! Iron fines; Solar Wind gases; silt for processing; Ag-grade soil; zeolite feed stocks (glasses) for agriculture filtration and insulation; gravel for lunacrete; chromium ores. We can obtain all these in the very handling of regolith, prior to all other forms of processing - including oxygen-extraction and glass-glass composites production.

For these collective First Fruits, I propose the term “Primage.” [Most dictionaries define this term solely as a safe handling bribe paid by a shipper to ship's captain and crew. But as a suggestive precedent, the O.E.D. also has: “the amount of water carried off suspended in the steam from a boiler” (about 3%)]

A Primaging 'Lith-Mover

Going through all the bother of careful regolith-primage, much like scraping and sanding the loose paint before repainting, will seem to most a thankless and unwelcome ritual. There will be a strong temptation to dismiss the need. But the settlement that adopts primaging as a transcendental imperative, will have a significant head start towards economic diversification and self-sufficiency.

Primaging could be the wellspring both of prosperous lunar industry and of productive lunar agriculture. Developing a practical, simple and rugged "Primaging 'Lith-Mover" should then be among our very highest priorities.

Developing the equipment to serve this purpose must be a high priority. **MMM**

LUnar
National
Agricultural
eXperiment
corporation
LUNAX

Logo by Fred Fleischmann and Peter Kokh Report by Peter Kokh

NOTE: The story of Experimental Lunar Agriculture may have begun with the Milwaukee Chapter of the National Space Society, but **this research has now resumed (2008) under The Moon Society.**

The Birth of LUNAX

There is a new kid on the block in the effort to pre-develop the repertory of technologies that will someday enable us to establish the sizable self-supporting settlements on the Moon that will at last make mankind a multi-world species. Some people, it is true, still labor under the assumption that such a grand goal is merely a matter of money, hardware, and national will. Leaving them to their comforting illusions, some of us in the Lunar Reclamation Society Inc., [M.L.R.S. incorporated under this name July 30th] have quietly started to peck away at the still growing load of homework that will really be necessary, in the hopes of finding ways to contribute which will test the limits of our collective talents.

In the process of working on our entry in NSS' Space Habitat Design Competition (1989) Lunar Base Category, alerted by a "whoa!" from collaborator Joe Suszynski of Chicago, the new Milwaukee Space Tech & Rec team [MilSTAR] identified one serious potential show-stopper. Unlike a smaller outpost probably powered by a nuclear reactor, a larger settlement may be economically strapped to use that energy available to it in as efficient a way as possible – at least until prosperity from trade reached a point where the settlers could burn up the ergs in a more customary carefree American style!

To get the community's vital food crops through the fourteen day long lunar nightspan with the same amount of light provided 'free' by the Sun during dayspan, would take a power generation capacity several times as large at that needed to take care of all the settlement's other needs such as construction, industry, transportation, air/water circulation and treatment, etc.

A Need to Experiment

Realizing that any settlement's success might in large part depend on knowing how little and/or how infrequently their plants needed a light-fix during the nightspan to coast until the next dayspan growth period – and still produce an acceptable harvest – our SSI support group, Milwaukee Space Studies Team (MiSST) put together a small pamphlet aimed at enlisting home hobby gardeners. "Guidelines for

Experiments in Lunar Agriculture" is slowly getting more exposure and sparking lots of interest. However, interest is painless (i.e. cheap). Taking the trouble to carefully perform these lighting experiments in one's basement or garage on a plant species of one's choice seems to be another matter. Simply put, the data from our rag tag green thumb army of enthused participants is not flooding in. We will need lots of data on lots of different plants. Even though it will not be possible to rigorously control experiment conditions, a lot of data might yet provide a good enough signal to noise ratio to enable us to pick out significant results from spurious ones. But how do we get that flood of data?

[Early Soviet experiments showed that if the plants are simply chilled to a few degrees above freezing, they would survive two weeks of darkness just fine, springing back during the alternating two weeks of light-feast to produce good yield. Eric Drexler, while still in high school, performed a similar closet vs. refrigerator type experiment with corroborating results. But even though temperatures would fall off once the Sun had set, at a rate that depended on the effectiveness of the insulation and the amount of the thermal mass within the farming unit, it might still take a considerable energy expenditure to induce the proper chill level, all at once, then maintain it – even if heat pumps were used to dump the heat into a eutectic salt or water reservoir from which it could be recovered near the end of nightspan, when heat was most needed. Chilling the crops may be one part of the answer – but we still need to know all our options!]

Getting Organized

To the rescue, LRS member-at-large David A. Dunlop of Green Bay, Wisconsin; I first met Dave at the 1989 Neptune/Triton Voyager Encounter party at the Fox Valley Planetarium in Menasha a year ago. Dave became quite enthused–about our Prinzton Lunar Base design study. That fall, he started making the long drive down to Milwaukee twice a month to take part in our brain-storming sessions on a possible book to expand upon our Prinzton study. These sessions would often last into the wee a.m. hours, after having adjourned from the Central Library's Old Board Room to the nearby I-Hop, or some all other 24- hour eatery.

When we took up the proposed chapter on Agriculture and the Biosphere, Dave became riveted on the challenge of the quite limited extent and rudimentary level of appropriate experience and knowhow available. Not only do we need to know all our lighting options, we need to know how to transform sterile Soil that has never known air or water into a medium that can sustain its crop yield season after season, not just once. We needed to determine what plants, and what microorganisms, would work together in a very limited ecosystem.

We needed to know a lot of things. And in point of fact, all we really know now is that we need to know one heck of a lot more! Late one evening, Dave called with a challenge.

We need lots of data and it simply isn't coming in from individuals. Why not organize the "Lunar Nightspan Hardiness" Experiment and perhaps some other suitable agricultural experiments and then enlist High School Science Teachers, with the hope of getting more data, and data of better quality?

Not being one to come up with an idea and then go hide, Dave immediately started networking, beginning with fellow Green Bay NSS member Neil Walker, high school science teacher. Through Neil, Dave got in touch with Ed Mueller in Neenah, Secretary of the Wisconsin Society of High School Science Teachers. Further calls uncovered considerable interest, even enthusiasm, for the idea.

Next Dave started calling select professional researchers in the field, with NASA connections, to solicit their ideas and comments. This was 'rough work', especially considering that NASA's efforts have concentrated on the food supply and biosphere needs of very limited small outposts - unrealistic models for what we proposed to do. Most of the Pros seemed to take it for granted that we'd have all the lighting energy we wanted on the Moon, and that crops would be raised in isolated and automated phone booth size pressure chambers. Once Dave backed up and explained to them our much more ambitious perspective, they showed a heightened interest, curiosity, and willingness to give advice and assistance.

Now that we began to feel confident that we had found a promising approach, the task became one of organizing. On June 23rd Dave and I drove up to Sturgeon Bay in Wisconsin's beautiful Door County, to meet his friend, attorney and Chicago restaurateur, Albert H. Beaver Jr. There in his office we drew up papers for a new nonprofit corporation, with the three of us as Directors, to pursue the effort to involve schools in those areas of Lunar Agricultural Research wherein the present rudimentary level of our knowledge still leaves room for meaningful school-level contributions.

A Magic Setting

Al owns a private resort, the **Chateau Hutter**, along the Bay shore, nine miles north of Sturgeon Bay, and we decided to use this "ideal" facility to host an “Invitational Workshop” for a short list of high school science teachers and professional researchers (some of these by teleconferencing) to carefully define an initial set of experiments, and establish an Advisory Board and Reporting System to keep the process going.

The 1st LUNAX™ Workshop-Conference was set for Tuesday thru Thursday, August 21st-23rd. Because it was necessary to limit attendance to a dozen or so in order to insure results, and because this brash initiative was not guaranteed success, we decided not to publicize the event outside the chapter. LUNAX I is now history.

Thanks to a truly magic mix of individuals of varied talent, endless enthusiasm and deep conviction, we succeeded in defining our goals and designing an initial 2- track set of experiments. The Lunar **Nightspan Hardiness Experiment** (here we are looking for the limits of crop failure) will begin with a practice run using Wisconsin Fast Plants' Brassica rape, able to go from seed to maturity in 28 days, and used in thousands of schools across the country. We will then seek to zero in on the nightspan hardiness of a wide variety of food and fiber plants that may make attractive candidates for the Lunar Biosphere.

We also prepared guidelines for an open-ended multiyear **Lunar Soil Evolution Experiment** using **MINNESOTA LUNAR SIMULANT** (here we are looking to find strategies for success). Three additional experiment tracks are in process of development, each of them aimed at supplying knowledge we do not now have, but which we will need if a “Return To The Moon to Stay” is to be successful.

Our purpose will not be just to teach already known space science. Rather, by reaching out through the hitherto untapped resource of H.S. Biology and Ag-science Teachers, we offer kids a "unique opportunity" to contribute brand new science of vital importance.

LUNAX' immediate task will be to gain experience with the initial experiment package worked out at Chateau Hutter, and to guide the follow up research, while continuing to define complementary experiment directions. A modest school Registration fee system will allow results to be gathered and analyzed, new experiment projects to be developed, and a newsletter (**Harvest Moon**) to be published. Individual hobby-gardeners and armchair fans outside the school system will be able to participate in or follow LUNAX progress. MiSST's pioneer work will be continued by LUNAX.

The challenge facing Lunar National Agricultural Experiment Corporation is an exciting one. While the work to be done is frighteningly enormous, the team gathered at Chateau Hutter begins with the confidence of being on the right track. MMM will keep readers informed with updates on our progress. We welcome this first addition to Lunar Reclamation Society Inc.'s new family of roll-up-the-sleeves partnerships. **MMM**

MMM #40 - November 1990

Cloacal vs. Tri-treme Plumbing

CLOACAL vs. TRITREME PLUMBING

CBy Peter Kokh

The Best Plumbing System for Lunar and Space Settlement Biospheres?

cloaca: (clo AH ka) = a common cavity into which the intestinal, urinary, and reproductive canals open in birds, reptiles, amphibians, and monotremes (the lowest order of mammals).

monotreme: (mo NO treem) = either of the two remaining species (duck bill platypus and spiny anteater) of the lowest, most primitive order of mammals, with one hole for all discharges.

SCENE: the lower Indus Valley about 200 miles NNE of modern Karachi, in the north part of Sind province, in what today we know as Pakistan.

TIME: some 4,000-4,500 years ago.

PLAYERS: a people, long since vanished from the area, but with increasing evidence that they were the ancestors of the populous dark-skinned peoples of today's southern India: the Dravidian speakers of Tamil, Telugu, Kanarese, Malayalam.

ACT I: fade from the ruins we see today, and known to us as **Mohenjo Daro**, back in time to one of mankind's first experiments in urban settlement - we do not know by what name its inhabitants called it - where the city fathers meet to accept the plans of their chief urban architect for the world's first urban sewer/drainage system: a network of gravity-gradient open ditches, into which all liquid-born wastes would flow off to same final place of out-of-sight/ out-of-nind.

ACT II: there never has been an ACT II! Ever since Mohenjo-Daro, except for putting the sewer and drainage system underground and treating the effluent so that it commits less aggressive harm against neighboring communities, we have been in the rut of the very primitive duck bill platypus, stuck using a cloacal system to handle the quite different wastes from toilet (septage), bath and laundry (gray water), kitchen, and industry.

Lessons for the "New Towns" of Space

Except in "new towns", it would be prohibitively expensive to switch to a new 'multi-treme' system which keeps different types of sewerage separate from the beginning in order to benefit from simpler and more efficient source-appropriate forms of treatment, with the fringe benefit of enjoying whatever valuable byproducts such separate treatment may promise. Lunar and space settlements are "new towns." Infrastructure is 'change-resistant'. Therefore it is of supreme importance to choose it wisely from day one.

While in many other areas NASA has chosen to pioneer radically new technologies, the agency, and those involved in the 1977 Space Settlement Systems Summer Study, turned instead to existing urban models when it came to the basic architecture of plumbing and sewerage treatment systems. If you think of the opportunities for Earth-side spin-offs, this tack emerges as a major slip-up.

Let's explore the benefits of an alternative triple conduit or tri-treme drainage and routing system for future off-planet mini-biospheres.

1) Farm, garden, and lawn run-off, food processing waste and kitchen garbage disposal waste (if not saved to compost for home gardens): the water laden with them should be kept separate by a distinctively labeled and color and/or design-coded drain and conduit system. After sieving out larger chunks for composting, such water can empty into fish tanks without further treatment.

2) Gray water from showers, hand- and dishwashing, and laundry would similarly have a privileged routing system, to a treatment facility, which would remove whatever biodegradable soaps and detergents are allowed, for composting separately. The remaining liquid could be run during dayspan through shallow near-surface ponds, top-paned with quartz, where 'raw' solar ultraviolet would sterilize it, killing all pathogens and bacteria. Simply cleansed and purified with the biodegraded cleaning agents added back in, this nutrient-rich water could go directly to farming areas and into the drip-irrigation system.

3) Septage (= urine and feces) can be handled next in several ways. The familiar very water-intensive water-closet flush toilet system could be preserved, connected to its own drainage net. Solids could be removed to be channeled through an anaerobic digester for composting and methane production [see "Methane" below], and suspended particles in the waste water treated by microbes to produce Milorganite™-type organic fertilizer. The clarified effluent would then go to the farm watering system. Or, the urine and fecal water might alone use a third drain line system, while fecal solids are 'collected' for separate treatment. [See "Composting Toilets" below].

4) Industrial effluent must be purified and reused in a totally closed on site loop with a high price for any loss makeup water piped in. Allowing industries to discharge water, of any quality, into the public drains system, invites than to pass on clean-up costs to the public. If all industries must play by this same rule, and cost out their products accordingly, there will be no problem with this make-or-break provision.

The 1977 NASA study recommended the use of a wet-oxidation (euphemism = incineration) process for treatment of all water-carried wastes indiscriminately.

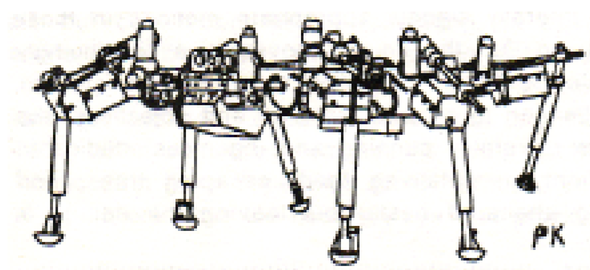
While this method almost certainly offers the swiftest turnaround for our costly original investment of exotic (= Earthsourced) hydrogen, carbon, nitrogen, and possibly added phosphorus and potassium, on the order of 1-1.5 hours, it misses valuable and elegant opportunities to produce 'organic' fertilizers and other regolith-soil amendments which are far superior to chemicals in their buffered slow-release of nutrients and in soil conditioning character.

In smaller space and/or lunar outposts, heavy reliance on chemical assistance for fast-cycling sewage treatment may be the only feasible way to go. But as we design settlements for hundreds or more pioneers, we have the opportunity, if not the duty, to consider more natural alternatives. Every part of our proposed tri-treme drainage and sewage treatment system, has separately received abundant proof of concept on Earth. **MMM**

NOTE: On the Moon we have a chance to start over. We can perfect the alternative tri-treme plumbing system in non-connected ex-urban developments. See this page on the importance of this:

http://www.holon.se/folke/kurs/Distans/Ekofys/Recirk/Eng/mifsla_en.shtml

MMM #45 - MAY 1991



"Atilla", a 2nd generation bug-like robot

Someday little but bug-smart robots like Attila and its predecessor, Genghis, may roam the storied ocher plains and canyonlands of Mars and other worlds, providing still-Earthbound humans with a lot more exploration data per buck. How far can we take these cute-ugly critters? The limits of "bottom-up" artificial intelligence may be well beyond current forecasts.

ROBO-ANTS

Helpmates on the Space Frontier:

A Constructive Look at the "Bottom-Up" Approach to Artificial Intelligence, Taking it to its Logical Conclusion.

By Peter Kokh

Several MMM readers have asked if we've been paying attention to work being done on 'robot insects' and the exciting possibilities for their use in prehuman exploration of Mars. Well we have, and frankly, we find the promise greatly underestimated. Here is our report.

The Topdown Model of Intelligence

At Massachusetts Institute of Technology, MIT, researchers pursuing robotic artificial intelligence have abandoned the conventional forbiddingly centralized, computer- and software-heavy, “topdown” approach to artificial intelligence patterned after the human nervous system and various problematic theories of how we perceive, think, and decide. Instead, led by Australian-born Rodney Brooks, they are taking their cues and clues from the very different architecture of insect intelligence.

Insects are highly successful at tackling complex feats on a routine basis despite their minimalist nervous systems and tiny brains. This is because, in bottom-up fashion, they operate by pyramiding more complex behaviors on simpler ones starting with simplest autonomous reflexes in individual legs and sense receptors. At each stage, there is no more coordination from above than there has to be to achieve a certain purpose such as walking or climbing or burrowing; and the animal’s brain is called into play only when stimuli and the need for appropriate reaction spill over certain threshold levels. By terracing simple steps, activities that would otherwise seem dauntingly complex, are easily handled.

So far, Brooks and his team have built Genghis and a successor, Attila, contrivances which both look suggestively insect-like, and behave in like fashion. They have multiple legs, each with its own autonomous microprocessor, segmented bodies, and stereo eyes. As each leg learns to coordinate with adjacent legs, the ‘insect’ gains skill in negotiating all sorts of terrain.

The robo-insect is meant to be an ‘idiot savant’, quite stupid in general, but extremely capable in a narrowly defined field of operation, in a caricature of contemporary human horse-blindered occupational specialization. Unlike today’s industrial robots which are designed to perform totally routine operations under identical circumstances over and over again, robo-ants should be able to perform a related suite of operations under widely changing circumstances, be mobile over unprepared terrain, and self-contained.

What’s more, these robo-ants can be built relatively small. Given limited payload and cargo capacity, we can land more of the little varmints on Mars (or wherever) and get back a lot more exploration data per buck, sampling more sites. Yet the excitement these prototypes are causing in the space community seems too restrained, conservative, and unimaginative.

Four main points, which we’ll explore one by one:

1) The insect is not the only, nor necessarily the ideal, model of bottom-up intelligence.
2) We must give correlative attention to sensory apparatus.
3) We need not stop the behavioral pyramiding when we have perfected a functional individual robo-ant.
4) There are even more helpful chores these little beasties might be able to tackle eventually beyond just exploring and collecting samples, and they can be tailored to toil in settings other than the surfaces of Moon and Mars.

(1) Another Model of Bottom-up Intelligence:

Our first advice for those researchers who want to explore the full range of possibilities that the bottom-up approach offers, and to become fluent in this ‘language’ and its idioms, is to consider the supreme culmination of individual intelligence in the invertebrate world: the octopus.

This curious creature carries some unfortunate and factitious evolutionary baggage that has kept it trapped at a level far below what its ‘alien’ architecture should have allowed. To give just two ‘for instances’, it has green copper-based blood (hemocyanin has only 1/20th the oxygen carrying capacity of iron-based hemoglobin, limiting its endurance), and the female lays swarms of minute eggs, wherefore, lest it eat its own young while they are too small for it to relate to, the female has been naturally selected to die shortly after the eggs are laid. Despite such handicaps, the octopus is far more capable of intelligently “manipulating” its natural benthic world than the more pelagic dolphin, the usual darling of popular esteem (the sea bottom being a more structured and intelligence-challenging setting than the open sea). In some still future time, it may be possible to correct some of the octopus's evolutionary missteps by genetic engineering (perhaps splicing in bits of genetic material from other mollusks with more desirable traits), and thereby set an altered cephalopod strain back on an upwards course with destiny (sophopods, the wisefeet?). But that's the subject for a Sci-Fi novel -- someday.

In the octopus, each tentacle explores rather autonomously, curiously picking up and examining by touch any food-sized object. The tentacle is good at sensing texture, but not shape, and can smell. Only when certain thresholds of stimulation are reached, does a signal go to the animal's brain. Similarly, each tentacle laterally signals appropriate motions in those adjacent, so that the animal moves in a convincingly coordinated fashion. The central brain is like a foreman, giving attention to general direction and objectives (the animal is extremely cunning and ingenious, dedicated and patient, in obtaining food, escaping traps, and preparing sheltered nests) but leaving the details of examination, handling, and locomotion to its tentacles.

Whereas, like 'intelligent' mammals in general, we have a "body image" by which we know where (orientation, direction, posture) our various body parts are (those subject to our discretionary control), the skeletonless octopus seems to have no "body image" at all. And perhaps as a consequence, it has no 'hand'-eye coordination at all. (This somewhat 'protean' shapelessness gives it the advantage of being able to squeeze its great head through almost any hole or crack big enough to accommodate the thickest parts of its individual tentacles – an enormous strategic advantage.) While the octopus is quite different from the insect, A.I. researchers might do well to study its highly adaptable bottom-up terracing of behaviors and its much greater capacity to learn.

(2) Refining Sensory Apparatus:

Attention has to be given not only to analogs of nervous systems, muscles, and bones, but to the sensory apparatus. Touch, for example, is a catch-all for separate but collocated abilities to sense shape, texture, hardness, wetness, temperature, and weight. If we can design robo-insect foot pads (or individual 'toes'?) with a set of receptors to do all of these, we will be getting off 'on a good foot' (pun intended). A sense of chemical taste should be included, designed to ignore the expected, and notice trace elements in unexpected concentrations. Rather than complex mass spectrometers, this might involve some suite of self-resetting litmus spots. On the other hand, a robo-ant need not have more sensory discrimination capacity than necessary to do the task for which it is designed.

Sight might be offered not only in a front-top-center stereo scanner on a stalk, but perhaps in a task-appropriate 'eyespot' on each foot, or forefoot, with the information not being called to the attention of the central processor and thus merit the gaze of the stereo-scanner, unless its content calls for organized response. In the octopus, the two eyes can cooperate or work separately when the situation allows divided attention. We tend to think two eyes are needed for range-finding (depth-perception) but one bobbing eye does just as well. We are currently at a juvenile level of playful fascination with a digital feast of irrelevant data completely overwhelming efforts at analysis.

An eye that can zoom

Researchers have to find a way to install data-filters that will ignore the non-significant and pick out the reaction-cuing patterns. Perhaps a good way to do this would be to give the eye "zoom" capacity, not just in magnification but in wealth of detail. In other words, a good eye for A.I. purposes, would sense only crude detail, but can "zoom in" in resolution, in spectral coverage (from black and white to special color filters, full colors, infrared, etc. as appropriate), and other vectors (polarization, shading contrasts, brightness, etc. etc.) when something "catches its eye", much like the comic strip hero Superman could "turn on" or "of" his X-ray vision. Thus we need an eye that provides a basic rough view, yet capable of considerable real-time on the spot image enhancement, triggered by the cues. What I would suggest is an underlying wide field of view with low resolution with a scanning focus/zoom device triggered through a series of data filters to 'notice' the unusual and unexpected, stop scanning and fix its gaze, focus, and zoom in for an enhanced view as per above.

A properly designed robo-ant would have specialized legs, perhaps all capable of supporting locomotion, but with some able to concentrate on examination of objects encountered, and others on transporting collectibles to a top-mounted bin or trailing wagon (which could empty its load when full, making piles for later pickup by a more capacious haywagon) or casting small 'obstacles' to the side.

(3) Cooperative Robo-Ants:

At least two dozen separate times in the history of insect evolution, the pyramiding of behavioral functions has spilled over from the individual insect into inherited cooperative social behavior totally beyond the capacities of the isolated creature. The prime examples, and those where the process has gone the farthest, are the social termites, ants, wasps, and bees.

In each of these cases, there is physical polymorphism within the species, that has gone beyond mere sexual differences and given rise to separate "castes" of workers, soldiers, drones, males, females, Queens etc. each of which have specialized built-in equipment and instincts, but together work cooperatively to achieve communal goals. Here there is no personal chain of downward command but rather a collective pyramid of upward input. Given these ample precedents, there is no reason why, once we've really mastered the business of terracing behaviors bottom-up style, that we cannot design our robo-ants in castes such that their specialized behaviors are pyramided to achieve really complex cooperative mission objectives.

ROBO-ANT CLASSES

A **Scout class** that explores, reconnoiters, classifies and marks the terrain it moves over, would come first. This is what researchers are aiming at now.

Sargents could direct deployment, ensuring full cover-age of a work area and act like sheepdogs, keeping units from straying. We can also have Harvesters whose job it is collect objects of interest noticed and tagged by the scouts or perhaps already placed in convenient 'hay bale' piles for later collection.

Refuellers or Rechargers could be on the lookout for stalled ants with an activated out-of-fuel or low-charge blinker. Retrievers could pick up disabled scouts and return them to the main staging area. Mechanics could affect simple repairs of disabled units, refresh their programming, or cannibalize them for parts.

Stragglers from other robo-insect collectives could be adopted and reprogrammed. Inspectors could accept or reject (undo?) work not up to their built-in standards.

A Queen or Mother unit, possibly atop a mobile hive-shelter to which individual ants could return at nightfall to conserve heat, to be recharged, to receive updated instructions etc. The mother unit need only recognize progress towards the realization of the collective mission, that is, able to send out a deactivation signal when the job seemed finished, spur on lagging castes, etc.

Communications between units and castes can range from plug-in electronic and/or radio debriefing or reporting to visual clues like variously colored lights flashing in repetitive coded patterns. On Mars, communication by sound might also be possible.

(4) Complex Missions for Robo-Ant Collectives:

Now for the rewarding payoff: once we have mastered the 'language' and idiom of bottom-up artificial smarts, extending it to intercommunicating polymorphic crews, to what use can we put this fluency? Exploration and sample retrieval are only openers, and unimaginative ones at that. Here are some more ambitious missions for our robo-ant teams:

Site preparation and pre-deployment tasks:

- Remove boulders from an area, grading and raking, for roads, skidways for craft landing horizontally, and pads for spacecraft landing on their retros.
- Excavate spaces for habitat modules, fuel tanks, etc.

- Collect regolith, load conveyors, and relay it as a shielding blanket over pre-deployed habitats etc.
- Identify desirable mineral and rock samples and pile them up for convenient later retrieval.
- Do pre-mining sortation, depositing richer concentrations of sought-after elements as 'leavings'.
- Sinter or gravelize 'porch' areas and approaches to minimize dust transport into habitat interiors.
- Set out tritium marker lights for roads, landing pads, and in lava tubes and other permashade areas etc.
- "Primage" lunar regolith for use as agricultural soil, sifting out ultra fine particles, and transforming glass spherules into zeolites to promote mineral ionization.
- Spin web mesh receiver antennas over suitably sized craters for radio astronomy and satellite solar power
- Survey/map lava tube complexes on the Moon/Mars.
- Harvest thin patchy water-ice deposits in lunar polar permashade not otherwise economically recoverable.
- Replace damaged panels in extensive solar arrays.
- Plug outguessing pores on comets in preparation for their shepherding to the Earth-Moon vicinity.
- Locate & map fissure escape routes for episodes of outgassing on the Moon seen as 'TLP' glows (Transient Lunar Phenomena.) Mark those where the volume of flow may provide an economic resource

Within habitat-biosphere areas:

- Tend farms, trimming dead leaves and stems, tilling, spot-watering, spot-fertilizing, detecting early signs of infestation, picking ripe produce, etc.
- Sort consumer and industrial recyclables
- Clean streets and other pressurized passageways
- Change failed or failing light bulbs and tubes
- Detect and repair minor slow air and water leaks In service of a future Mars terraforming effort:
- Locate and pre-tap areas where water-ice permafrost rises closest to the surface.
- Physically, and even chemically (where possible with non-consumed catalysts), condition raw soils, sands, and gravels for the introduction of microbial cultures
- Channelize potential canalways (identified by orbital altimetry mapping) from polar to equatorial areas; and channelize the 'saddles' between neighboring unlinked basins to accelerate development of a mature drainage system in expectation of future rains.
- Out Among the Asteroids and Comets
- Locate, map and presort and/or pretreat surface-available mineral resources
- Pre-mine desired resources on small astrobergs so that only resource-poor tailings need be used as mass driver pellets in coaxing it into a handier orbit
- Locate intact remnants of impacting bodies
- Look for 'parent-body' tell-tale signatures
- Excavate pressurizable galleries for outposts
- Produce fuels from otherwise unpromising fields of volatile-rich materials
- Make and cache 'bricks' and other simple building materials in advance of crew arrival
- Locate outgasing pores or vents on comets during their dormant phase
- Tunnel to the core of comets, analyzing the material all along the route

All of the above complex activities can be analyzed into a pyramid of simple tasks building on one another, and we should be able to design and program robo-ant teams to handle any of them with a minimum of human supervision or monitoring. In each case, given the higher cost of alternatives, the lower degree of accuracy, consistency, and coverage, and generally wider specification tolerances that bottom-up tasking can achieve may be acceptable. But surely, the above suggestions do not exhaust the possibilities.

There are a number of reasonably analogous sites on Earth where such robo-ant teams could be field-tested and given prior experience. The lava tubes of the Oregon Moon Base outside Bend, Craters of the Moon National Monument in Idaho, Antarctica's Dry Valleys all come to mind. But for many applications a scattering of less unique places including abandoned mines and quarries should serve as well.

"Social" robo-ant co-ops promise to become our indispensable helpmates in opening up the space frontier on the Moon and Mars, on asteroids and dormant comets, and even in free space construction sites, concentrating on tasks of limited complexity in life-hostile surroundings to relieve exploring pioneers and settlers of high-risk drudgery. As such, they could be the Army [Ant] Corps of Engineers of the future.

With a little imagination, there should be Earth-side applications aplenty for profits here and now, from robo-ants designed and engineered now. So perhaps some of you will be motivated to get in on the ground floor. We hope so! <<< MMM >>>

MMM #49 - October 1991

Biosphere II, and III, and IV and …

On Thursday, September 29, 1991, the long-awaited and repeatedly delayed moment finally arrived for eight "Biospherians," four men and four women with genuine bravado, as they stepped across the threshold into what in effect is another world. That Biosphere II ("I" being Cradle Earth itself) is physically located on the planet's surface instead of some point removed, does not invalidate the heady claim. Excepting electrical power and telecommunications links, the umbilical cord to Earth is being broken for the first time, however tentatively, however experimentally.

Many pouting second guessers, not having had the foresight, ambition, inventiveness, or drive to have done something similar themselves, are faulting the project's design, specifically the complexity of the 5-biome (ecosystem) linkage and the ambitiously large number of plant and animal species included in this first test. Others, playing dirty hard-ball, attempt to find skeletons in the participant's closets. Have scientists now sunk to the pettiness level of politicians, or what? - that's scary! Our reaction is unprintable.

In simple point of fact, while most space development supporters (and societies) continue to invest their energies as if the lack of the lack of the needed space transportation infrastructure hardware is the only thing standing between us and our fondest dreams, we 'ain't' going anywhere in any real way until we've learned to set up autonomous biospheres that work.

And "work" is the operative word. We were angered by ABC's story subtitle "science or showmanship." They completely miss the point. While Biosphere II hopes to shed much light on a plethora of ecological and environmental questions, the whole point of this unprecedented exercise is not "know-what" but "knowhow." In this sense, Biosphere II should be seen more as a biosystems engineering test than as a scientific experiment.

The odds are great that the eight colonists aboard this dry-docked ark will not be able to complete the full 2-year intended stay before their mini world becomes unbalanced in some way from which there will be no recovery without stop-test intervention. Does that mean failure? Hardly, The only engineering experiment that can be called a failure is one from which nothing is earned, a highly unlikely outcome.

That Biosphere II is being done with private money ("tainted" to many scientists used to the federal dole) and that marketable results will be proprietary (for sale or license) angers many. But it should cheer the most of us, for at last we see private enterprise and the profit motive beginning to apply its sleeping do-all might.

At the National Space Society Board of Directors annual meeting in San Antonio, May 26th, Directors were asked to suggest magazines in which NSS might advertise in the hopes of recruiting more members. Alas, the tired litany of suggestions – science, engineering, computing magazines – gave a discouraging impresssion that many board members still believe that hardware development and procurement is our principal, if not only concern.

We finally got our two cents in, pointing out that we must live in viable mini-biospheres if our presence in space is to be truly enduring, and that therefore we ought to include publications in the fields of biology, botany, ecology, agriculture, and environment. We've made the point before, but except for a few like-minded spirits, we are still the dreaded 'fringe', not the mainstream of NSS thought.

What the Society needs to do, beyond the positive articles in Ad Astra on Biosphere III and related topics, is simple:

I. Actively recruit new members in the field of life sciences, ending this stupid nuts and bolts chauvinism.
2. Go on record as encouraging and supporting entrepreneurial research and development of biosphere systems in general (it would not be appropriate to stand behind Biosphere II specifically, however much we all hope that this first test advances our bio-engineering knowhow).
3. Back this up by developing legislation that will give tax-breaks and/or shelters to each type endeavor.

Admittedly, this will be hard to formulate. Pointing out the potential payoffs to "Biosphere I" (as well as to prospective off-planet communities) will be the way to sell it. A tall order? Let's all keep in mind, nay, dwell on the fact of space life, that we're not going anywhere, except to picnic and come home once again, unless (or only to the extent that) we've mastered the complex challenges of establishing new mini-cradle-earths to support our multiple transplantations off-planet, be it in moon bases or space colonies. **PK**

MMM #60 - November 1992

Xities* Beyond the Cradle: Unaddressed Challenges

* Pronounced KSIH-tees' not EX-i-tees

Beyond-the-cradle off-Earth settlements ("Xities") will be fundamentally different from the familiar "Biosphere-I"-coddled "cities" that have arisen over the ages to thrive within the given generous maternal biosphere that we have largely taken for granted. Elsewhere within our solar system, each xity must provide, nourish, and maintain a biosphere of its own Together with their mutual physical isolation by surrounding vacuum or unbreatheable planetary atmospheres, this central fact has radical ramifications that must immediately transform space frontier xities into something cities never were.

By Peter Kokh

Pushing the Envelope

To many people, space enthusiasts are a strange lot. Sure, we all see plenty of room for improvement in living conditions here on Earth, but Earth is our only uninterrupted prehistoric and historic home. It seems unnatural or escapist to daydream and dally about new home settings beyond the natural integral, seemingly holistic surface of Earth. Earth is the "world" and everything beyond is but lights in the sky.

"World" can be defined philosophically as an integral or integrated complex of horizons, each leading into the other. The forest leads into the savanna, the savanna into the desert, the desert to the coast, the coast to the sea, the sea to other shores – embracing at last the entire surface of our home world. But the actual sense of "world" has already gone through a series of explosive expansions and logistical integrations. Our "civilization" (from Latin civitas, the city) is fast becoming a "Planetization."

In the course of this history, various exploring and expanding civilizations have renewed themselves and escaped stagnation of spirit, both collective and individual, by pushing their individual envelopes. Nothing could be more natural than for us to continue this process beyond "the Sky Barrier."

Dreamers have long imagined beachhead settlements on the surface of other celestial bodies: the Moon, Mars, the great moons of Jupiter and Saturn, even (naively) on Venus. Gerard O'Neill, and Dandridge Cole and John Bernal before him, exploded the timid limits of our vision to include space settlements organized around gravity-mimicking centrifugal force on the inside surfaces of rotating hollow spheres, cylinders and toruses. A few have talked about atmospheric settlements. The common thread has been that these locales are all beyond the clench of our atmospheric benefactor-jailer.

This is not to say that the current envelope of our planetization cannot be expanded right here at home. Seafloor settlements have stirred the imagination of many from the days of Plato's tale of mythical Atlantis and of Jules Verne's novel "20,000 Leagues Under the Sea", to ex-Mercury astronaut Scott Carpenter, and to the current League of New Worlds efforts (Challenger Station and Atlantis) in Florida.

Many space activists show marked impatience with this avenue of expansion. Witness the recent exchange of opinions in **Ad Astra**. Yet seafloor outposts provide a handy analog of space and planetary settlements. Many of the umbilical cord-cutting technologies and tricks we need to master can be developed and debugged in submarine settings – indeed it is hard to imagine a better and cheaper and safer place to perfect our know how in pressurization, closed loop life support methods, and general self-reliance. Thus this disdain or annoyance is a sad testimony to the superficiality and self-defeating impatience of many space enthusiasts. We'll succeed in space only if we have taken due time to do our homework. We desperately need to embrace this opportunity.

Yet pushing the envelope of the human range is not just a matter of technological gee-whizzery. We propose to go not only "where no man has gone before," but "where life itself has not gone before." We would not only leave our cities but the encradling global biosphere Gaia whom we can take for granted no more. The biospheric challenges are even greater than the engineering ones. Yet somehow most enthusiasts seem to think all this will just somehow fall into place once we have cheap access to space. The techno-fixation of all pro-space advocacy groups (NSS leadership and membership alike decidedly included) shows that down deep, most of us are not really emotionally ready to be weaned from the Gaian teat.

Yet our rallying cry is "Ad Astra!", "To the Stars!" Indeed given that the Sun and planets are formed from the ashes of generations of long dead stars, such a presumptuous journey would truly be an epic pilgrimage home. Such a journey, like all others, starts with a first step. We have to be patient with our baby steps if we are to make it all this way. We need to tackle the many unaddressed challenges of our determined migration off-planet. Here are some.

Xity Construction and Maintenance

Off-planet settlements or xities must first of all do an effective job of containing a breathable atmosphere. We know how to make small pressure hulls, somewhat. The Shuttle, for example, leaks at a rate that would create an unacceptable air-replacement burden at the distance of the Moon or beyond. We need to do better. And as we move from simple structures to complex ones integrating a number of modules and pressurized connectors in a uni-atmospheric maze, the criticalness of adequate joints, seals, and vibration-hardiness will grow acute.

Space Station Freedom could have been a learning experience in this regard but we have chosen (is it really a choice when nothing else is even considered?) to use seals and sealants that can be manufactured only on Earth rather than develop and test those that could be duplicated in early settle-ment technology reliant on locally available raw materials. NASA's charter R&D mission is unthinkingly mistargeted, given our stated goals. Thus early outposts on the Moon will succeed merely in giving us a totally unearned sense of achievement, setting us up for eventual and certain failure.

The growth or expandability of surface and space settlements is an important topic we've taken up in previous articles. It is a challenge for engineering, for biospherics, and for economic and cultural health. We have few good answers.

Initial Challenges For Biospherics

The obvious purpose of extraterrestrial mini-bio-spheres is to provide sustainable and adequate fresh air and water and food for the inhabitants. Many would reduce this to an agricultural equation. What can we grow in a given climate to provide a varied and balanced diet? But we will also need other agricultural products: fiber, pharmaceuticals, household preparations, cosmetics, and industrial-chemical agents and feedstocks for which it is not yet feasible to produce an inorganic substitute based on local raw materials.

Further all the plant and animal species and varieties we need for all these purposes must co-exist in some sort of feedback balancing ecosystem. Further, even if we are eventually successful in meeting all these design goals, our mini-biosphere will likely be unequal to the task of keeping the air and water fresh. We need an unexpectedly and discouragingly large a biosphere in ratio to the size of pioneer population to be supported. That Biosphere II is having problems maintaining oxygen levels without CO2 scrubbing is an important lesson and achievement of the experiment.

The health of the biospheric environment aside, our confident expectations that humans can adjust to significant fractional gravities like that of Mars (38%) and the Moon (16%) are yet to be validated. It is not only the physiological health of the original settlers that is in question, but that of their first and successive generation offspring. Here, aside from the limited predictive value of experiments with artificial-g and generations of short-lived fruit flies aboard Freedom, there is little we can do but dismiss all hesitation in getting our feet wet. A bureaucratic ban on pregnancies on the Moon or Mars will be immediately and directly self-defeating.

Because of the possibility of eventual isolation and an interruption in immigration, initial genetic diversity should be prudently given priority attention.

The Aging of the Xity

We have barely begun to experiment with creation of mini-biospheres in the hopes of coming up with families of sustainable mini ecosystems. But ecosystems, like individuals, mature and age and either adapt or die. We haven't the foggiest idea how quickly or tolerably a mini-biosphere would age and its life-sustaining effectiveness degrade. With so much need for experiment, the temptation to criticize and dismiss the only ongoing experiment we have, Biosphere II, is criminal.

Vulnerability to microbial sports and accidentally imported unwelcome microbes and pests is a make or break area for research and brainstorming. The umbilical cord with Earth may be cut, but as long as there is trade and travel, settlement biospheres will be at risk for critical disruption.

Xity and World

Stagnation within the change resistant limits of fixed size settlement megastructures promises to be a real problem. Initial picture postcard beauty of settlement interior vistas may be achieved with deceptive ease – akin to what we now do in zoos. But over the long haul, the vitality of self-renewal and self-redefinition with the option for growth will be much harder to realize.

Clustering is one answer to xity stagnation. An effective “world”-plex of neighboring xities within which cluster travel is relatively easy, will do much to provide the relief of change of scenery, import and export of fresh ideas and methods and products. It is questionable if an isolated xity can remain socially and culturally sane. Surface networking of a plurality of xities on both the Moon and Mars are essential. But the same case must be made for effective clustering space settlements. Our off-planet communities will sink or swim by their inclusion in workable new “worlds” made contiguous through trade and travel.

This networking will become strained as we move out to the Asteroid Belt and beyond into the Outer Solar System. Electronic networking will have to carry the load. But eventually sheer distance and associated time-lags will strain that accommodation also.

Logistic and Other Trade Challenges

Not only will xities need to band together to keep their civilizations healthy, they will need to do so for sheer economic survival. It is estimated (please don’t ask me for a reference) that at today’s level of material civilization, it takes a community of a quarter million (250,000) to support an economy diversified enough to supply 95% of its own material needs. It will be some time before we have individual off-planet communities of that size, let alone an aggregate of several settlements totaling that many souls. Even then, trade for that stubborn 5% of their self-unmet needs will be vital.

Earlier milestones of say 60% self-manufacturing can be met with far smaller populations. But then the need for existence-sustaining trade will be that much greater. This will put a priority on substitutions, making do, and doing without that would strain the gung-ho spirit of today’s crop of Earth-spoiled would-be volunteers. Where export-import logistics are difficult, strained by high energy costs and/or infrequent launch windows due to shifting orbital alignments, imports must be planned ahead. Stocks of replacement parts must be maintained with religious care. There may have to be a brash acceptance of medical triage. The Moon is just seconds away by talk, a few days by walk. But replacing things on Mars and ordering things that have been inadvertently left out of original supply endowments will involve demoralizing delays. And beyond it gets worse. All the more need to set up a diversified multi-xity Martian (or asteroidal) economy without hesitant delay.

The Xity and the Stars

Science Fiction tradition is already rich in stories of interstellar arks containing whole ecologies and civilizations bound for prospective settlement locations around strange exotic suns light years away. This tradition was reinforced in the seventies with the development of the Space Colony concept. Space Colonies founded within the Solar System might presumably get bored with the challenge of life around our native star or become disenchanted with the prospect of continuing contact with the rest of Sun-huddled humanity, pick up anchor and sail for greener pastures and virgin sunlight.

In a very real sense, every off-planet xity will be an ark both for its human population and for its human-tolerant ensemble of plants and animals. The difference will be that the degree of required self-reliance will be “within reason”, that the degree of discontinuity with fellow circumsolar xities will be forgivingly less than absolute.

Yet these Sun-bound communities will serve to provide a preview of the “foresaker” spirit star-bound folk will need to display in uncompromised measure. Xities beyond Mars will demonstrate major reliance on electronic intercourse and carry self-reliant ingenuity to new heights of virtue.

We may never actually set out for the stars, and if we do, it may be by sending one-way seed and spore banks, not communities of actual individuals. That is, humanity and Gaia may reach the stars by “propagation” rather than “travel.” If so, it will be because in pushing the envelope, xities have come up against limits to independence asymptotically impossible to attain or exceed. Xities will be nonetheless star-bound spores of the human spirit. As such they will be the ultimate manifestation of the root "star-drive" within us. **PK**

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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 undertaking, 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 unthreatened 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 Lunar

Industrialization of the Moon

INDUSTRIALIZATION

Cons, and Pros, of a Planned Lunar Economy

By Peter Kokh

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

BENEFICIATION

By Peter Kokh

Making rich “ores” out of very poor ones

ben e fi ci A 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, FeTiO3, (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

MAJOR (pph) MINOR (pp10t) MICRO (ppm)

* 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 He4, Ne, Ar, Kr, Ze, **He3**

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 or 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

SINTERED IRON FROM POWDER

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

By Peter Kokh

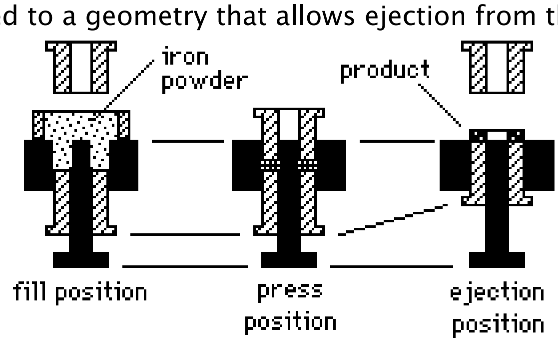
The Lunar crust is about 44% oxygen by weight, yet surprisingly, it is still appreciably underoxidized. Every available atom of oxygen is chemically bound up in the minerals of the crust and regolith soils derived from it without exhausting the opportunities for oxidation. The evidence is unmistakable. 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 thou-sands 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 aero-space 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**

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

GLAX 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 fiberglass reinforced plastics, we will be poised to "self-manufacture" 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" pages 6-7 above.]

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

GLASS

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 commercial 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 crystallization. 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_2O_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_2O_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_2O_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 producible on the Moon. It does, however, include 0.8% B_2O_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_2O 15.2%, CaO 7.4%, Al_2O_3 4.4%,
K_2O 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 secondary ingredients that regolith processing must produce (in addition to the abundant oxygen, silicon, calcium, aluminum, iron, magnesium, and titanium). **MMM**

CERAMICS

CERAMICS By Peter Kokh

ce RAM ics: [Greek [illegible] – 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 with-drawing 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**

color the Moon
“anything but gray”

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. Fe_2O_3, 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 copper-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 copper 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 needs to 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 coaltar 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 to paint 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) water-glass based naturally flat whitewashes. While experimen-tation 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: [PS] 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**

MMM #64 - April 1993

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 homesteads 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

1: Farms for Food Staple Production Self-Sufficiency, sized for local settlement consumption.
2: Farm Expansion to serve Food Export Markets elsewhere on the Moon and in Space.
3: Farm Expansion to supply fiber and other nonfood but fully biodegradable and/or recyclable uses.
4: 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**

MMM #65 - May 1993

Lunar Industrialization: Part II By Peter Kokh the substitution game

THE SUBSTITUTION GAME[TH]

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 above.], 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 2-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 diversification 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 substitutions 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.

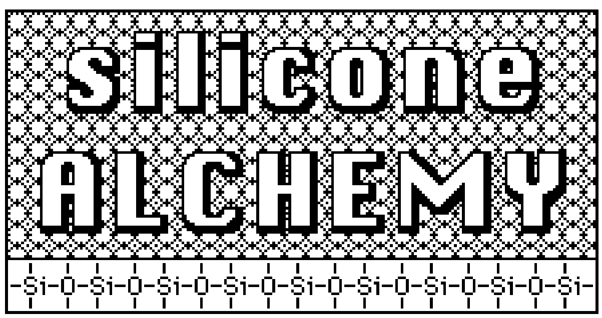
We can use alternative packaging materials made of metals or alloys embodying Lunar deficient elements. We can also formulate them out of hydrocarbons and other volatiles. If we are especially determined to tilt the game, we might go much further and consider which parts of Earth-Moon vehicles and their 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 eco-system. 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**



SILICONE ALCHEMY

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.

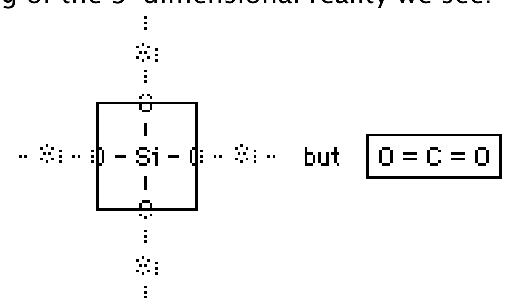
Those elements that have 1 to 3 electrons in the outer shell are metals: they ‘lend’ these ‘extra’ electrons to other atoms lacking a corresponding number, the nonmetals, thus forming chemical compounds linked by “covalent” bonds.

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.

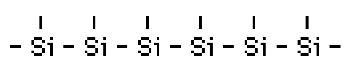
Both silicon and carbon have a tetrahedral tendency: they tend to form four chemical bonds in three dimensions oriented towards each apex of a tetrahedron with the atom at the center. Back in the nineteenth century chemists first started to wonder if they could construct a silicon-based "organic" chemistry 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.

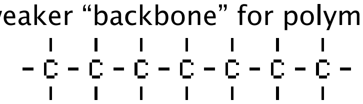
Unfortunately there are critical differences and the first clue to that should have been as obvious as night and day. Consider carbon dioxide CO_2 and silicon dioxide SiO_2. One is a gas with a very low freezing point, the other a solid (sand, quartz, glass) with a very high melting point. They could 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 $Si(1/2O)_4$. Looked at in a 2-dimensional rendering of the 3-dimensional reality we see:



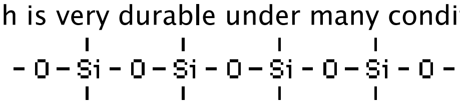
Actually, the hydrides of Silicon behave more like those of boron (with a +3 valence) than those of carbon. The two (Si, B) are similarly very reactive to oxygen, water, and the halogens (chlorine, fluorine, etc.) Even in compounds where they each (Si, C) form only single bonds there is this significant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

Lunar and space pioneers need an non-prohibitively 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 non-prohibitively 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 some-one(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

SULFUR: 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 seal-ants. 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 ornamentation that can be colored; with sand, and gravel for street pavement; with sand to be cast into floor slabs and sidewalk 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 polysulfide, and as an additive to polystyrene and polymethane 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 resistance 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 developers. 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

MOONWOOD: FIBERGLASS SULFUR COMPOSITES

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 - 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 skim oat 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 backer board for ceramic tiles, even in wet area applications like showers and sink back splashes.

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

t o n s MUS/cle g r a m s

MUS/cle 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 [see pp. 8-9 above.].

The MUS syllable 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 person power 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

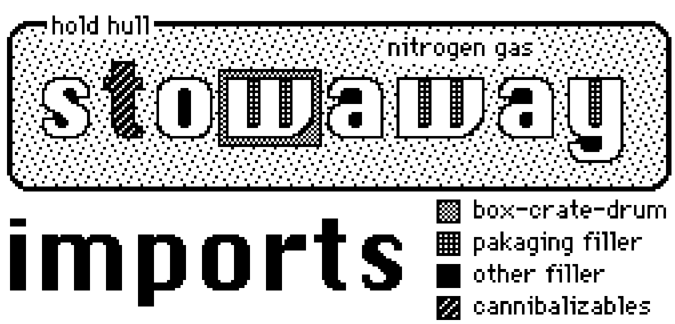
To maximize the potential, it may well be necessary to do some serious industrial redesign of the items in question to better segregate and maximize the potential “MUS” components, and to better integrate the remaining “cle” components in “works cartridges” for subsequent labor-light mating and assembly 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**



STOWAWAY IMPORTS

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 re-outfitting per flight could actually be less than the customary one-time individually customized outfitting that is 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 replacement 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 coimports "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**

MMM #66 - June 1993

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.

utilities infrastructure

[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

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

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 small 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 super-conducting 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

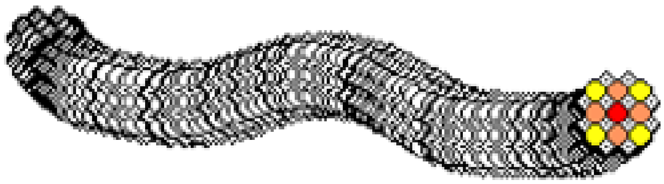
Not only must utility system components be selected, and in some cases even redesigned afresh, to permit local manufacture of as much of the system mass as possible, in other cases whole new approaches must be adopted (per the examples above, using gasses to virtually transport water and power). In every 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" MMM #40 NOV '90 p4 .// MMM Classics #4]. Hydro-Luna will also be aggressively involved in finding new cheaper sources of water, or 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.

Superconductivity on the Moon



Uses and Obstacles

By Peter Kokh

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 diagn ostics, in gyrotron radio frequency devices, in ore refining, and in research on magneto-hydrodynamics. 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 magneto-hydrodynamics), 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 super-conductors 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 super-
conductive 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, V3Si, 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 La2-xBaxCuO4, 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 settlement 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**

WIRING THE MOON

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

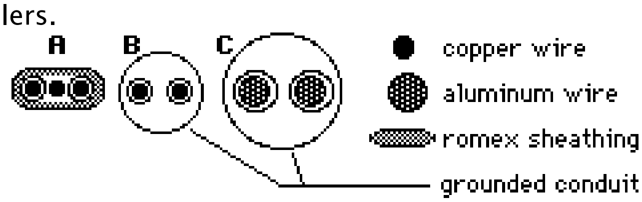
By Peter Kokh

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.



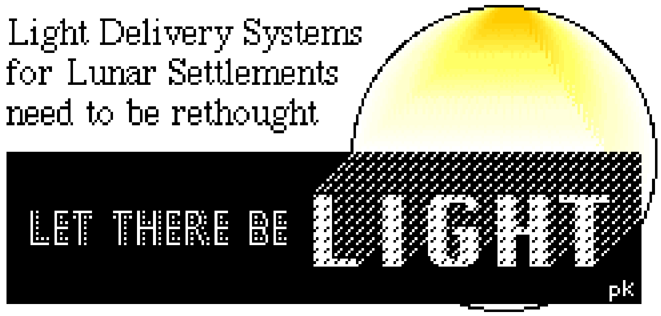
KEY: A. Modern flexible plastic sheathed ROMEX cable
B. Rigid or flexible grounded conduit, copper wire
C. The same with aluminum wire

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 thiosilicone (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**



LIGHT DELIVERY SYSTEMS FOR LUNAR SETTLEMENTS NEED TO BE RETHOUGHT

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.

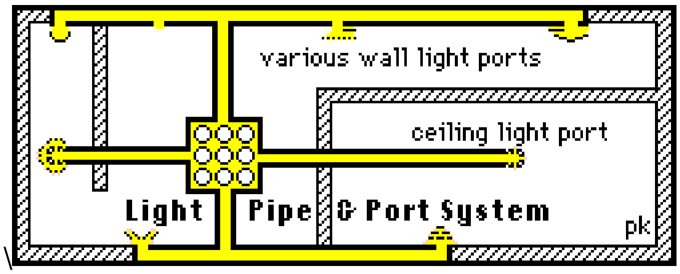
Our familiar everyday **incandescent** light bulb is quite reliant on tungsten wires and filaments for which there is NO practical substitute. The amount of tungsten involved is, however, trivial, and could be affordably imported, preformed and ready to be assembled with Made-on-Luna glass bulbs and 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 person power.

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 Company 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” [page 5 above.] 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 hardcopy supplement to hardcopy 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 poster boards.

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

ENCYCLOBIN

"A question of not wasting spent person power"

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 - July 1993

In Focus Editorial (excerpts)

“Demo of Die!” - Advice with a Warning

Perhaps the one achievement most responsible for the early creation of a strong pro-space constituency in the US, and even beyond, was the development at Princeton University, under Dr. Gerard O’Neill, of three successively more powerful working prototypes of a “mass driver,” an electromagnetic payload accelerator, which Dr. O’Neill saw as a necessary element in the future use of vast quantities of lunar regolith by space manufacturing and construction industries.

Since then, many interesting paper studies have been forthcoming, but very few “demos” of “critical” systems and hardware needed to put humans into space in large numbers.

If we are to have a significant enough effect on the powers that control decision-making in this country, we need to get back to the business of demonstrating item by item, each engineering and technology piece of the Space Settlement Scenario puzzle. Without demos, the future we paint for the public and our leaders alike lacks convincing oomph - believability.

Not even all the disparate space organizations in this country acting together in some too-good-to-be-true coalition can field the whole complex of equipment needed to open the space frontier. That would take megabucks beyond our collective power to raise, or spend.

But while we cannot build full-scale operational hardware, in many cases we can build small-scale demo units that convincingly demonstrate critical principals and aspects of technologies that would thereupon beg government funding for further development. The ground floor is always the cheapest, and for many of the engineering developments foreseen as necessary, nothing at all has been done beyond paper studies. We can find our niche here. And if we don’t move to occupy it, it stays empty.

Shy of demonstration, the specter of unknown but possible showstoppers looms to demolish confidence in the future, playing into the hands of those with other priorities for public attention - and spending. Given today’s climate in which the momentum of space development is clearly falling off, we must either work to “demo”, or we’ll surely see our dreams die.

Space Studies Institute maintains a list of “critical path” technology items that seem to be within reach of low-cost demonstrations: the production of an “ice-cube-sized” sample of glass fiber/glass matrix composites by Brant Goldsworthy for example. But there is too much to be demonstrated for anyone to relax, knowing that SSI is on the job!

The Planetary Society had surely contributed a share of technology demonstrations. TPS worked with CNES, the French Space Agency, and with the erstwhile Soviets to develop, test, and debug the “Snake” – a ground tailing and probing tail for the balloon probes being readied for the Mars 1994 mission. Nor did they dip into general funds for this, instead writing a grant proposal, and getting it funded by CNES, Has the National Space Society been as bold or imaginative?

Nor need space technology “demos” be undertaken as an NSS-wide Headquarters- or Board-supported effort. Some orphan technologies will benefit from initial concept demonstrations requiring funs small enough for chapters to leverage. Not all of these opportunities will be along the “Critical Path.” But no matter, the potential effect on the public could be great.

The list of opportunities is only as short as our imaginations are stunted by disuse. For motivation, consider that every spring the National Space Society hosts the International Space Development Conference in a different city each year. Is it not time to make thee invigorating events something more than the presentation of teasing paper studies; something more than a chance to network in the hallways between talks? Why not make the ISDC a demo-unveiling event as well? **PK**

Industrial Grease

industrial Grease: Hydrogen: The “Water-Maker”

Hydro Luna

MISSION DIFFICULT: Supply Enough Water to
A Parched World to enable it to Grow and Thrive.
By Peter Kokh

NOTE: This was written before confirmation of abundant ice deposits at the lunar poles

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 H20 instead of H2 alone" - versus "how much (energy and amortized capital equipment) does it cost to free O2 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 CH4 and Ammonia NH3 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 well-head 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 "aero-braking." 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 "cold-trapping" 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.

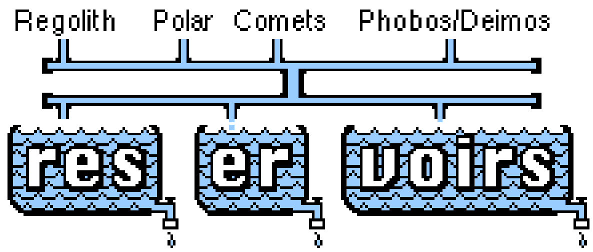
Volatiles to be shipped to outlying sites in steady-enough and high-enough volume can be piped. For this purpose methane and ammonia would be best. They are easily handled and can be "burned" efficiently with lunar oxygen in fuel cells to produce welcome power at the final use site.

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. **MMM**



RESERVOIRS 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. 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 coharvested 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-conser-ving 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 [above], 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. **MMM**

Xeroprocess

XEROPROCESS

xe ro- (ZEE ro): from Greek ξερος, “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. Xero-processing 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 brain-storming 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. **MMM**

MMM #79 - October 1994

Vehicle Design Constraints

pk

VEHICLE DESIGN CONSTRAINTS

Overlooked Lunar Vehicle Design Constraints

By Peter Kokh

It might seem that designers and engineers of vehicles meant to roam the lunar surface have a clean slate. First, there is no atmospheric drag with which to contend, therefore a need neither for streamlining nor for a low, narrow cross-section profile. Second, there are no real estate expense reasons to keep road rights of way and traffic lanes as narrow as those we are well accustomed to on Earth. Lanes, and the vehicles that ply them, could be radically wider — So it would seem. In reality, some relevant considerations are important enough that real constraints on vehicle design emerge.

Dust Control → "Dustlining"

The Apollo Astronauts found the powdery lunar dust to be quite troublesome. In short, they had a "static cling" problem. We should be concerned with two things; first, dust working its way into moving vehicle parts, compromising their smooth operation and operating life. Second, we need to minimize the migration of dust into habitat areas.

While electrostatic control may indeed be part of the solution, we'd do best to approach the problem from redundant overlapping angles. In the latter case, we need to minimize or altogether prevent foot traffic from the outvac into the habitat areas. Where some in and out space-suited traffic cannot be avoided, paved or "fixed" porches and approaches will help for pedestrian and vehicular traffic alike.

As for the vehicles themselves, the underside can have a dust-shield pan that minimizes the number of catch basins for vacuum born dust. On Earth, streamlining has affected most the frontal and upper surfaces of a vehicle. On the Moon, a somewhat analogous dustlining will affect the frontal and lower surfaces. We must learn a new, yet familiar, set of tricks.

Saving atmospheric gases → "Snuglocks"

There is a seemingly limitless supply of Oxygen on the Moon. But the point is that the high lunar vacuum is an invaluable scientific and technological resource. It pays to do everything possible to minimize any slow degradation this vacuum will undergo from repeated airlock cycling.

More importantly, however, at least in its immediate economic ramifications, is the principally exotic, or Earth-sourced nature of the Nitrogen we will need as an atmospheric buffer gas, one with biospheric importance as well. In short we need to conserve both oxygen and nitrogen. One way to do this is to use matchlocks instead of airlocks for the delivery of goods and personnel between the exterior vacuum and the pressurized interior. Direct docking allows shirtsleeve passage.

Those who must enter and leave, either the vehicle or habitat, on foot, can use turtleback suits, backing into a form fitting lock. Once secured with a pressure seal, first the concave mini-door to the habitat opens, then, into it, the conformal back of the turtle back space suit. The occupant reaches backwards inside the habitat for a bar above the turtle lock and pulls him/herself through the turtle back into the pressurized habitat. The dusty suit remains outvac. The back of the empty suit, then the door lock is closed, and the empty suit moved by a robo-arm to an exterior storage rack

More salient here is the periodic need to bring vehicles into pressurized garages through large airlocks. The only way to minimize volatile loss in this case is to design vehicles so that all top and side-mounted protruding equipment retract into hollows in the hull, even the wheels can tighten up for the taxi in, so that the vehicle fits through a much smaller standard size garage airlock as snugly as possible. This snug-lock would have a conformal antechamber exposed to vacuum, so that when the airlock was opened, vehicle in antechamber, the outrush of air would be minimal. In other words, the type of vehicle we need as a mainstay is a "Snugger."

Ease of Maintenance → "Modular Drive"

There will be times when repairs must be performed outvac, far from a friendly snuglock. Much difficulty can be avoided if all repairable equipment was part of a modular pop-out/snap-in subassembly. For example, an electric power unit in a removable tray could feed power to four independent motor-wheel drive units that could in turn be switched with one of a pair of spares in a few minutes, the particular item needing repair to be taken care of later in a pressurized garage. Similarly, air/water/waste-recycling systems should be in easy to exchange pop-out/snap-in trays.

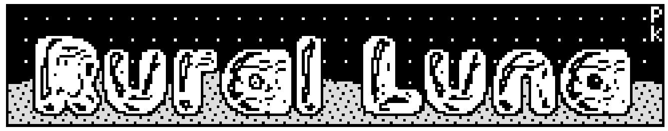
Road worthiness → "wide, low, shielded"

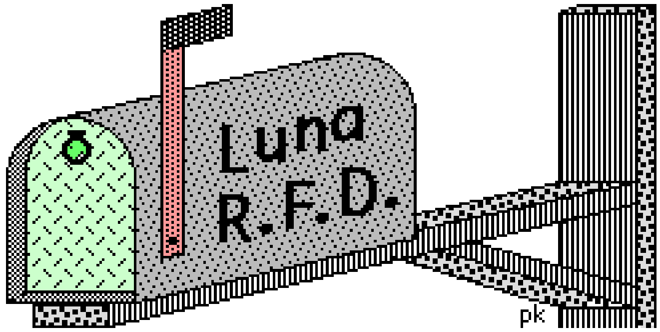
The salient features of the lunar motoring environment in addition to its dustiness are the low 1/6th Earth-norm gravity or sixthweight, and vulnerability to occasional deadly solar flare storms. To tackle the first, the wheel units, vehicle outside the snuglock, should extend well to the side, reptile style, rather than below, mammal style. Road lanes can be as obligingly large and accommodating as pragmatism demands.

In addition, given the equally reduced traction, the center of gravity must be kept as low as possible, even though ground clearance may need to be generous, especially for off-road vehicles. In this latter case, a vehicle can ride low when the path is relatively level and boulder-free, and then automatically rise up to clear obstacles picked up by its proximity sensors. For vehicles that spend their lifetimes on improved roadways, the problem is minimal. The wide track, a cabin slung between the wheels, and common sense positioning of heavy equipment and fuel tanks will keep the center of gravity low enough.

For unpredicted solar flare emergencies, there could be a movable rack of empty tanks, normally kept topside, but deployable over the aft end when the Sun was lower to the horizon. Fuels like hydrogen and oxygen and fuel cell waste water could be pumped to these tanks as needed, the vehicle parked, its butt to the Sun, covered. Having more heavy equipment over the rear axle, compensated by cantilevering the control cab over the front axle, should help. **MMM**

MMM #81 - December 1994

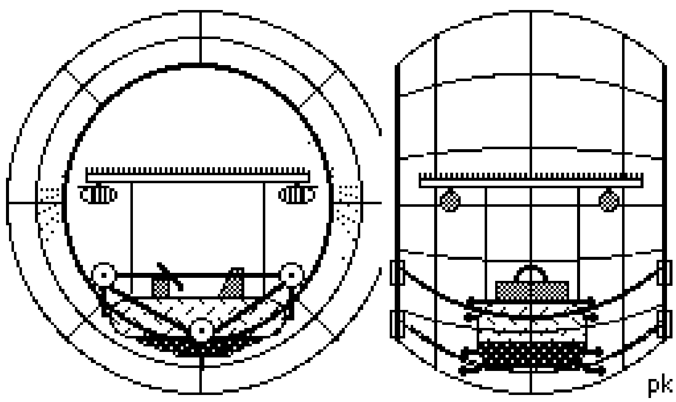




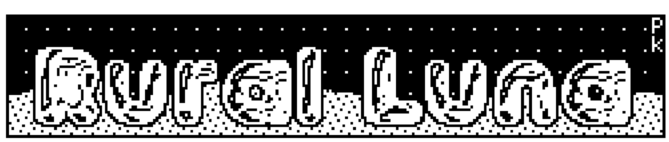
RURAL LUNA

Lunar “surrey with the fringe on top”

Watched “American Gladiators” lately? Have you seen the “Atlasball” segment? Next time picture space suited lunar thrill-seekers working their geodesic cages along a rally course of craterlets etc. Might be fun if the sweat of exertion and the overheating inside one’s space suit could be handled!



Similar solar powered spheres could be equipped with a track riding buggy capable of generous side-to-side movement or banking. Such an “off-road vehicle” - call it a unicycle, an auto-tracker, a cyclotrack, or whatever - could open the vast lunar barrenscapes to the sports-minded “outlocks” types and help avoid cabin fever. More on Lunar vehicles below.



RURAL LUNA Part II. Surface Vehicles & Transportation

By Peter Kokh

Travel on the Moon, or Mars, won’t be as causal as on Earth for a long, long time to come. Nor will there ever be as many modes. On the Moon, air travel is not an option, and reliance on suborbital rocket powered hoppers would increase the strain on the quality of the vacuum, a unique industrial and scientific asset worth preserving at any cost and inconvenience. On Mars both of these options are open and viable. In this article, however, we are concerned with ground transport.

Getting from here to there over the lunar surface, or over the Martian surface for that matter, poses an interesting set of challenges. The most obvious of these, negotiating the trackless terrain, is the one that has received most attention. Innovative wheel/tire designs and terrain-hugging suspensions are what we have come to look for. In recent years with the exploration of the possibility of microrobotic rovers, walking contrivances and computer programs to operate them have been added to the repertoire.

A few years back, OMNI Magazine offered a $500 prize for most innovative lunar rover design. Here too, the process of negotiating the terrain received the most attention. There have been some distracting bugaboos. For example, the OMNI requirements included a provision that the vehicle be able to handle crevasses. Sorry folks, but apart from the ice caps on Mars, "there ain't any"! At the same time, some very real, very salient challenges have received very little attention.

There is more to a vehicle than its interface with the ground! Other considerations need to be addressed:

√ **The temperature range** over which the vehicle must operate: on the Moon, from 200 some degrees below to more than that above Zero Fahrenheit; on Mars, mostly in the colder part of this range. – Note that the Apollo rovers were operated only during the dayspan. This means special heat and cold-resistant lubricants must be formulated, perhaps that special bearings must be designed. It means that batteries and/or fuel cells must either be thermally well insulated or be designed to operate in extreme temperatures. Siliconized lubricants, super-conductive magnetic bearings, and thermally insulated power plants would all seem to be a part of the picture.

√ **The distance range** over which the vehicle can operate without returning to base. Where time is not a consideration, a vehicle powered by solar arrays can operate continuously from shortly after sunrise to shortly before sunset some fourteen days later, then sleep through the two-week long nightspan. It's range is not limited. But except for robotic exploratory and/or drone freight vehicles, time is a consideration. Speeds must approach those the terrain will bear. And nightspan travel may well be required.

Solar arrays may be used as auxiliaries but stored electrical power such as fuel cells may be primary. Another option is chemical power using "fuels" derived from the surroundings on route, for example powdered pure iron fines extracted from the soil, burned in oxygen. To our knowledge, no one has as yet been thoughtful enough or inventive enough to attempt developing the engine required. Once we have such an engine, a refueling depot infrastructure will be needed to allow indefinite ranging.

Certainly, like it or not, for free ranging capability uncoupled to refueling depots or caches, nuclear electric motive power is a prime option, that is, if suitably sized lightweight yet full-shielded units can be engineered. But that will be quite an engineering challenge.

Beamed Power

Yet another range-expanding option is beamed power.

Background: For fleet vehicles operating in the immediate vicinity of a main base or settlement, power generated by whatever means can be beamed from a high tower to any non-occulted vehicle within a local range of several miles. [See the suggestion of Myles A. Mullikin in MMM # 31 DEC '89 "The Laser Power Tower" p. 5. - republished in MMM Classics #4, page 9] Such an arrangement could cover construction vehicles, delivery trucks, spaceport coaches, etc. The rooftop rectenna would be much lighter in weight than the alternative bank of fuel cells or batteries. While the beam could be adequately safeguarded by fail-safe feedback loops, the capacity of the power tower to feed a growing fleet of vehicles at different vectors all at the same time, is unknown.

Such a setup could terrace the way to the introduction of global beamed power from solar power satellite relays. This would allow unlimited free ranging. The problem here is that solar power satellites would have to be stationed in L4 or L5, the closest stable Moon-synchronous positions, some ten times further from the lunar surface than similar satellites in geosynchronous orbit are from Earth. Given the fall-off of power with the square of the distance, that's a hundredfold handicap to overcome. SPSs in L1 or L2 only twice as far out as Geosynchronous Earth Orbit (only four times as handicapped) would require enormous resupplies of station-keeping fuel. And the problem of feeding many vehicles all at once with individual tight beams is the same.

It would seem then that there are just three really practical systems: (1) free-ranging larger nuclear powered craft; (2) vehicles burning powdered metal in oxygen limited to routes for which intermittent fuel resupply has been arranged; (3) fuel cell powered vehicles, also limited to serviced routes.

As has happened on Earth, there will be an evolving mix of vehicles of different types and those that work most efficiently and conveniently and inexpensively and reliably will become the standard. Again, as on Earth, there may be exceptions for local fleets where special support infrastructures might make sense, offering economies of opportunity.

√ **Consumable reserves** also limit the effective range of crewed vehicles. Air and water must be recycled and regenerated on board, probably without bioregenerative support except in larger craft. As to food, reliance must be on compact rations unless caches or depots have been arranged along the route. This limitation applies to otherwise unfettered nuclear craft as well.

The upshot is that travel over trackless areas, far from serviced routes, will be as non-casual as in similar situations on Earth, e.g. early Antarctic expeditions. Could one possibly have expected otherwise? **MMM**

Over-the-Road Long-Distance Trucking & Rigs

By Peter Kokh

Other than the cowboy, few occupations have been so romanticized as that of the over-the-road long-distance trucker. It is a calling definitely not for everyone, keeping one away from home and family for long periods of time. Of course, one end run around this drawback is the husband and wife trucking team which provides not only conjugal company but relief behind the wheel, even around-the-clock driving.

There is a romance about the road. It differs, of course, depending upon whether one plies a fixed route over and over on a week-in week-out schedule or ranges all over the map picking up cargoes of opportunity. In the one case the litany of truck stops and other diversions becomes routine, in the other it always keeps changing, though its poetry is the same. Inevitably one gets to know many others in the trade and it truly becomes a way of life - in the blood, as they say.

Truckers drive by day. They drive by headlight. They drive by radio, and by CB, and now cellular. They reckon by rote, by map, and now by Global Positioning Satellite systems. They acquire their handles, name their rigs, and their lore is mythologized in many a melancholy tune.

Many a business is at their service: motels, garages, restaurants, and complete truck stops; hookers on CB, radio stations, tractor customizing shops, custom apparel makers. Many a time myself on the highway day or night between country cottage and city four hours apart, I'd spot the Moon in the sky and wonder: "will it be the same up there?" Surely, not at first. But then the driving influences, the incentives, the needs – they'll be there unchanged. At first it will be lonely out vac, carrying a load the interminably long empty miles from Port Heinlein to Clarke City through grayscape after grayscape against black star-rich skies, and even lonelier by nightspan. But inevitably, eventually, it'll be " on the road again ."

Distinctive features of Lunar Rigs

The Cab has to be/to do a lot of things. It must be pressurized, thermally well insulated, and provide for routine activities: sleeping, eating, hygiene, first aid, entertainment, communications, and more. Obviously we'll need more than a pair of seats and a bunk. In contrast to the current luxury super cabs of many modern long haul truck rigs, the cab of the lunar rig will have to be a camper-sized cocoon, a traveling truck stop, to use an oxymoron. It will be "self-contained", have walk around space, a galley area, a lounge area, maybe even a spare berth or two so that the rig operators can offer "tramp steamer" type accommodations to occasional passengers.

As to the **cargo bed**, this can be either pressurized or not, depending on the cargo (cf. the distinction between refrigerated and non-refrigerated trucks). If pressurized, it is likely to be separately so. The twists, turns, torsion stress and vibration that comes with movement over a surface that is not straight, flat, and level would tax any connection critically. There would be match -lock pressurized access to the hold only when the truck was parked, straight and level.

The cargo area may have an accessible solar flare storm cellar at the bottom so that any cargo carried could act as shielding. The cab-cocoon itself may have a storm cellar cubbyhole in the floor area, beneath water reserve tanks, fuel cells, and other heavy equipment.

Rig class ratings will tell the type of routes the rig is able to handle: unimproved but scouted routes, graded routes, routes with tended way stations or refueling stations, fully serviced routes with staffed service centers, etc. in declining order. This will work to prevent both operator and customer from undertaking foolish ventures.

Rigs will be largely self-servicing. They will be equipped to **self-unload**, with their own forklift or crane. Cargo will be containerized as much as possible to allow easy, fast, low-risk, low-exposure loading and unloading. The rig would boast a strategically-stocked parts bin and tool crib.

Rigs will be designed and engineered for **easy self repair**. Pop-in/pop-out independently-suspended wheel/drive-motor modules might be the rule, each getting electric power from a central plant. Each rig might carry a spare module, with standardized replacements available at service centers. The rig would carry a piggyback open rover **dingy** for emergency travel and capable of transporting replacement parts like wheel/ drive modules.

Communications: both audio (radio) and video services will be possible either via L1 relay, or direct from Earth. A low orbit satellite network is not an easy answer. It would be prohibitively expensive to maintain because the perilune or low point of low lunar orbits decays too quickly towards inevitable surface impact. Entertainment and news casts especially packaged for lunar truckers, if originating in the main or other settlements via L1 relay, could conceivably be a favorite eavesdrop for their earthbound counterparts.

Trucking in "deep" Lunar Farside, the 60° orange slice over the horizon not only from Earth but from relays in L4 and L5 as well, will require special communications arrangements. Perhaps a **roadside cable** with intermittent very-short range transmitters would allow one-way or two-way radio exchange say every few miles or every 15 minutes or so along the route.

Autopilots may be as popular and common on the Moon as cruise control on Earth. For there will be much less traffic; the slightest road jam will be fare for prime time newscasts less obstacles. The contingencies will be more routine. Autopilots may even be necessary for safety. For the very infrequency of situations requiring unprogramed on-the-spot reflexes or reactions, along with the monotony of the scenery, unbroken by human-made structures and artifacts could tend to be very soporific.

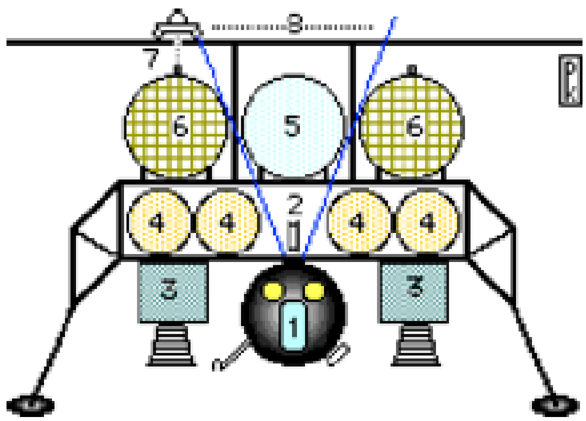
Once their are a number of real settlements, there will be carriers who make the rounds, plying the circuit to pick up unordered specialty consignment goods in each community to make available in all the others. These "**Gypsy Traders**" will have pressurized holds and back up to settlement match locks in the "market " area. Arrivals will be well publicized. The holds may contain their own display space, or else goods to be merchandised may be prearranged on rollout display carts and cases. Items will run the gamut from arts and crafts furniture, furnishings, giftware, souvenirs, and apparel, to home-canned specialty food items not otherwise available.

Servicing smaller less self-sufficient outposts and stations will be **traveling clinics** equipped for routine surgical procedures and other treatments. An ophthalmologist/ optician will be along. But these clinics will not be limited to medical practice. On the staff will likely be troubleshooting experts on agriculture and gardening, on recycling systems, and on biosphere maintenance. A dietitian will help plan strategies to meet deficiencies and other problems in the local diet.

A social worker and psychologist will be in demand, for lunar frontier life will have its share of stresses as well as rewards. An educational specialist will consult with outpost tutors. A writer/journalist will gather material for a round-robin news feature magazine and may need a sketch artist/ photographer. A specialty barber/hair stylist may have plenty of customers for non-routine makeovers. Etc. [See MMM # 35 MAY '90 "Tea & Sugar" pp. 6-7 for discussion of a similar traveling clinic/general store making the rounds between asteroid outposts.]

There will be lots of interesting jobs and occupations on the space frontier. One of them, offering relief from cabin fever within the settlement will be overland truck driving. However, settlements may need to train a large surplus of qualified drivers. Because of the **occupational hazard** of accumulative radiation exposure, overland outgates driving will be only a part time occupation. Each driver will wear a bracelet that indicates accumulated rad exposure. Hired drivers and independent rig-operators alike may be scheduled to drive only a few months each year, alternating with another line of work, an ideal regular shot-in-the-arm morale booster. Or they may be scheduled to make but one round trip each lunar month. Such a situation will spur the rise of **Coops** of Independent Operators and co-owned rigs. At any rate, there should be no shortage of candidates. **MMM**

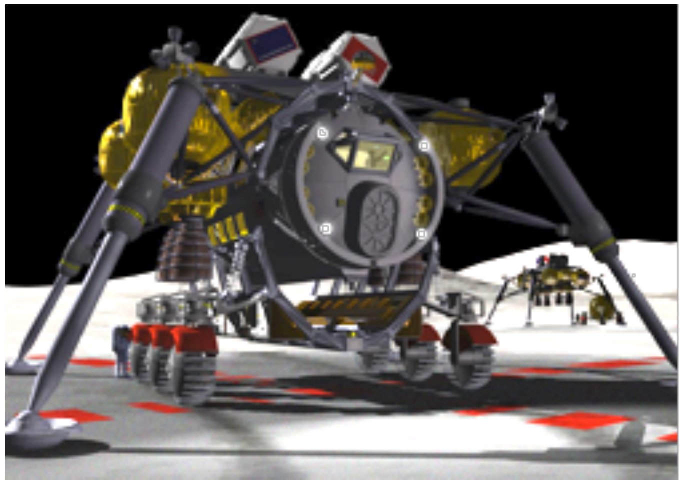
Toadmobile Conversions



KEY:
1 Frog (detachable mobile crew cabin) wheel on right retracted, wheel on left extended
2 Winch to lower/raise frog 3 Main rocket engines 4 Fuel tanks - 5 Oxidizer tanks

6 Cargo pods 7 Overhead crane/winch for cargo 8 Central clear-vision area for top viewport navigation

Frog vs. Toad: The Frog concept is an "amphibious" lunar lander. The crew cabin comes with a retracted, deployable wheeled chassis which upon landing is winched to the surface, allowing the "frog" to drive itself to an outpost already deployed. After the visit, the frog would drive itself back to the lander for the return to an orbiting station. This concept was presented in a paper at ISDC 1991 in San Antonio, TX and has since been further developed by NASA. See illustration below.



http://www.patrawlings.com/images/large/S183.jpg

The Toad is a logical development of this concept. If the descent/ascent stage could be designed to take off without the crew module, picking up a new one at LLO or LEO. The original crew compartment vehicle would continue to serve as a lunar surface transport. This "toad" version would require a more rugged chassis, more serviceable engine, and some sort of refueling arrangement. If we are to settle the Moon in a self-leveraging way," toads" introduced to serve remote outposts, may be the ideal 'dues-paying' way of importing the surface craft needed before the settlement is able to self-manufacture its own coaches. Whether crews came through open space or across lunar terrain, the vehicle that actually couples with the outpost structure will function as a surface coach at the time.

Designing "Amphibious" Spacecraft Cabins to be transformed into Lunar Surface Craft

By Peter Kokh

The problem is easily stated. Our first returning crews will need surface transport on the Moon immediately. Further, as the base expands and undertakes more activities, its surface transport requirements will grow and diversify rather quickly. Yet the day when such vehicles can be manufactured on site is far off. How do we get these craft to the lunar outpost site in the most economically sensible way?

Consider that a lunar surface craft is still a spacecraft. It has to have a vacuum-worthy pressurized hull, have thermal control, micrometeorite protection, full radio communications, power reserves, etc. etc. The lunar surface, after all, unlike that of our home planet, is an interface with vacuous space itself. It is not the pressurized cabin that differs, but the motive chassis. In the one case we need rocket thrust propulsion, in the other we need wheels or legs. At least the cabins can make the trip to the Moon carrying people.

One can enter this in the books in either of two ways: (a) the fares of Moonbound passengers pays the freight bill on the transport cabin; (b) the passengers ride free or at reduced cost, almost as stowaways, the bill being paid by the agent ordering the vehicle for lunar surface use.

Thus at least some Earth-Moon passenger cabins will in fact be built for “amphibious reassignment.” Those with designs maximized for freight hauling, or for equipment-laden field trips with minimal crews, are likely to be reassigned upon completion of their first outbound trip. Those designed as passenger ferries may serve in this capacity for a good number of round trips, and then “retired” to surface duty as a “coach” after being mated to new ground-chassis in a final overhaul just before its last trip out from Earth orbit.

How many trips could such a cabin make before being reassigned to the surface? This would vary as the average crew stay time lengthens and as the number of people coming out to the Moon each month grows in ratio to the number returning home. For example, instead of each ferry returning to Earth at 75% capacity, every fourth ferry landing could be a final one, with the cabin wheeling off “into the lunar sunset”, while the other three returning home full. Or in other words each ferry would make three round trips, followed by a final one-way trip, to drive happily ever after over the moonscapes.

Obviously, this process can either be allowed to just “happen” or it can demonstrate a great deal of forethought. For example, ferry craft can be designed to optimize their usefulness as lunar surface coaches, at least where doing so would not compromise their safe functioning as a ferry en route.

The same double service design principles can be applied to pressurized holds as well as to crew and ferry cabins. We will need such holds and ready-to-outfit hulls on the Moon, as well as en route. Other lunar surface needs will be rather specialized and make for less than ideal ferries. Yet they need not make the journey out empty. Perhaps cabin importer and passengers can split the savings. Beside mining crew, road-building crew, inter-settlement, and spaceport coaches, say in the 20-50 seat capacity range, we will need mixed passenger/freight vehicles and trucking rig cabins meant for one or two people, crane cabins, cabins on regolith moving equipment, etc.

But we will also need cabins that are towed to a site and semi-permanently parked as construction shacks, film-making headquarters, prospector camps, etc. Indeed, such sedentary usages may account for a large part of the demand. Clearly, there is the need for a great deal of preplanning if surface needs are to be met in a “just-in-time” fashion. Space-craft production without forethought to their eventual longer term aftercareers would be foolish, and work to hamper and drag down the growth of any outpost or settlement. **MMM**

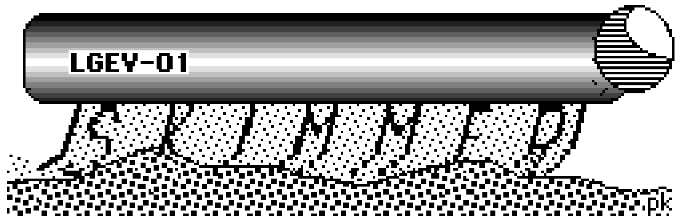
Cf. Section “Hostels: Visiting Vehicle” online at:
http://www.moonsociety.org/publications/mmm_papers/hostels_paper.htm

Beyond the Beaten Path

Having to restrain the globalization of the human presence on the Moon and Mars to the pace of grading/building conventional road networks would put a real damper on the rate of growth of Lunar development and industrial diversification. Yes, conventional “off road” vehicles can be used. But they will be both slow-going and constrained to the more “negotiable” routes.

Below we examine some less conventional vehicles that could help quicken the pace of world building on the Moon, and Mars too

The “Skimmer”



By Peter Kokh

Given that there is no atmosphere of consequence on the Moon, and precious little on Mars, the idea of using "hovercraft" or Ground Effects Vehicles to traverse off-road routes on either of those worlds is patently absurd. Or is it?

Yes, of course, we can't just apply power to a downward ducted fan on a flexibly skirted vehicle and expect it to go anywhere. But it is not the ducted fan but skirt-contained over-pressure that is the essence of hovercraft. On both worlds, both because the gravity is less and the prevailing atmospheric pressure is lower than on Earth, the amount of trapped pressure needed to produce adequate lift will be much reduced. And conceivably at least, there may be a couple of ways to effect just such weight-compensating overpressure. All that is lacking is inventiveness, simulation, and testing. Skimmers could provide the key to the globalization of the human presence on the Moon; on Mars as well

The market for a practical system could be rewarding in both locations. Skimmers could navigate rugged trackless boulder-strewn terrain at greater speed and comfort than any wheeled or walking vehicle. If practical and economically feasible to engineer and manufacture, the timely introduction of such skimmers could provide the key to the globalization of the human presence on the Moon and Mars, greatly reducing the need to grade/build extensive road networks, and helping preserve the lunar terrain in a more natural, wild state.

Terrestrial applications sufficiently profitable to drive "spin-up" predevelopment of analogous fanless craft on Earth in the near future are possible but admittedly not obvious to the writer. We welcome your suggestions in this regard.

Chemical propulsion for lunar skimmers

On the airless Moon, gas pressure retained under a ground-hugging flexible skirt can be produced by any rocket type thruster. Obviously we do not want either to be importing fuels for such purpose or to be using a combination whose vital working exhaust remains volatile. The ideal solution may be an engine burning powdered lunar-mined metal in lunar processed oxygen. The exhaust, having done its lifting work, will settle back to the ground as an iron or aluminum oxide powder. That may visibly mark the path taken but hardly contaminate it any sense of the word.

Such engines are yet to be engineered, even though the chemical possibility has long been known. One big potential problem lies in the weight of the fuels to be carried and/or the need for an infrastructure to provide for convenient en route refueling. While the range of the fully fueled Fe/O or Al/O lunar skimmer will be limited, one must bear in mind that since only a sixth the lifting power required for a similar craft on Earth will be needed on the Moon, a full tank will go for a surprisingly long way.

Dust-Pressure Skimmer Systems

Very large lunar skimmer craft more like barges than trucks or busses might be able to handle the lunar gravity reduced weight of a small submarine type nuclear propulsion plant. The power generated could feed a laser rake or sweep just to the rear of the front skirt, the effect being to stir up a lifting cloud of regolith dust, possibly enhanced by released fine-adsorbed gasses when traveling over virgin terrain. Would the lifting power so generated be sufficient for the job, marginal, or totally inadequate. We don't know. Back of the envelope guesstimates from readers are most welcome.

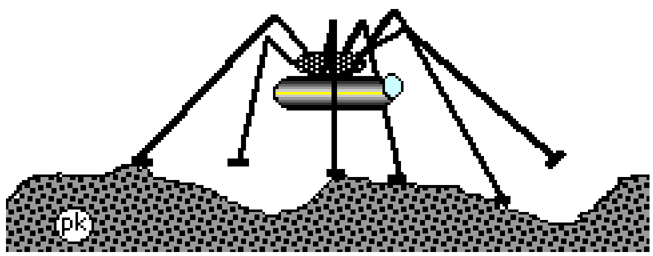
If such regolith dust-cloud pressure is just marginally adequate given the weight of the nuke plant necessary, one solution may be to substitute beamed power from a solar power relay satellite. Beam driven skimmers could be a long time coming, waiting upon a space power infrastructure.

Skimmers could serve as personal transport, as trucks for priority shipments to isolated outposts, as go-most-any-where platforms for selenologists (lunar geologists) on field trips, and for prospectors. They could also serve as rescue craft and ambulances.

Skimmers will be limited in what they can carry, at least relative to their own mass, size, and hovering thrust. But that constraint applies to most any vehicle, even on Earth.

Very large skimmers with broad beams could serve as "mare cruise ships", leaving "wakes" but no tracks on the long frozen lava seas of the Moon, leisurely making the rounds between ports of call. They could import much of the romance, lore, and mystique of Earth's high seas. Why not? MMM

Go-anywhere 'Spider' with Suspended Crew Cab



By Peter Kokh

Much of the Moon's surface, especially in the "Highlands", is very rugged. A vehicle modeled after a "Daddy Longlegs" or "Harvestor' spider would be able to traverse such terrain with ease, and probably at a respectable gait. The crew cab being perched well above the surface would provide a commanding perspective of the surroundings, and allow a better choice of path to blaze ahead. A computer program would run the legs, allowing the crew to concentrate on the surroundings. A further advantage is that one or more Spiders would allow explorers to visit much of the Moon's "out-vac" back country (and the rugged lunar Farside) without having to build roads, leaving the visited areas in their pristine state.

One model from nature of a creature that can go just about anywhere is the spider. I have in mind particularly the mobility architecture of the "Daddy Longlegs", in some places known as the "Harvestman." Might not a lunar (or Martian) traveling conveyance of similar articulation and ability become an indispensable asset in opening up the more difficult reaches of both frontier worlds?

The Spider's "body" would consist of two separable components: the "trunk" would contain the "hips" for the six legs and associated "musculature", and the power, fuel, and motive plants. Underslung by a "dead man's winch" would be the crew cabin. This position gives it shielding protection from the locomotive complex above as well as an unobstructed view of the terrain below. If power should fail, the crew cabin would automatically winch to the surface in a controlled descent. This deployment could be overridden, if there was any reason to remain aloft.

The scale of such a contraption could be rather large, in fact the larger the better within practical limits. The legs could be long enough to elevate the central pod complex some dozens of meters above terrain obstacles below. This height would also be of great advantage in scouting a pathway ahead.

The spider gait could bionically mimic that of real spiders and include a cautious grope as well as a trot of sorts when the going permits. All it takes is a computer program.

The feet, the knees and hips as well, could be sensor laden, feeding back first to neighboring and partner legs, then to the central nerve center. In this respect the model might rather be the loosely decentralized manner of the octopus.

Difficult Terrain Exploration

In the saturation bombardment craterland of the lunar "highlands", it is in general possible to make one's way by sticking to "intercrater" plains, ridges, and shoulders, avoiding steep inclines. But what if we want to visit the central peak of a debris- and boulder-strewn crater such as Tycho?

On the maria, the darkish solidified lava sheet "seas", the going is generally easier, craters of size being fewer and further in between. But even the flatish maria are laden with obstacles such as sinuous rilles (relics of large collapsed near-surface lavatubes), lava sheet flow front escarpments, "reefs" of incompletely buried pre-flood "ghost" craters, and of course the ramparts of "coastal" impact-upthrust mountain ranges. Such obstacles could make circuitous detours the norm rather than logical straight line routing - that is, if we are traveling by vehicle with limited ability to negotiate rough terrain.

On Mars there are similar relatively smooth and relatively rough areas, and similar obstacles. To be added in the mix are difficult landforms unknown on the Moon: crevasse-ridden layered polar ice caps, eroded slopes of the great shield volcanoes, dendritic tributary and distributary channels of ancient river and flood courses, chaotic labyrinths and canyon-lands. Many of the geologically and/or mineralogIcally (thus economically) more interesting spots on Mars lie smack in the midst of such harder to reach places.

Cache Emplacement

A go-anywhere spider vehicle could do preliminary geochemical assessments along its route, and emplace seismic monitor stations. Where such dust and rock samplings warrant, it could then put in place handy base camp supply caches for follow-up field expeditions and prospecting efforts.

Construction Crane Workhorse, the "Webspinner"

A heavy-duty version of such a straddle-anything pick-its-way-anywhere vehicle could serve as a crane. As such it could do yeoman work in relatively urban settlement sites as well as in remote construction locations, becoming in this version the workhorse of lunar development, as well as scout. Specialized versions could spin arrays of cables across craters to make radio telescope dishes and space-solar-power rectennas. They could also spin cables across rilles from shoulder to shoulder for bridges or to support habitat meta-structure roofs. Indeed, it is hard to see how we could long manage without them. **MMM**

[Shelterless Travel]

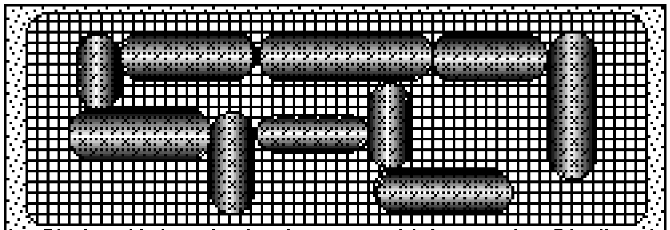
CAMPING UNDER THE STARS

Roughing it for real!

By Doug Armstrong and Peter Kokh, CCC

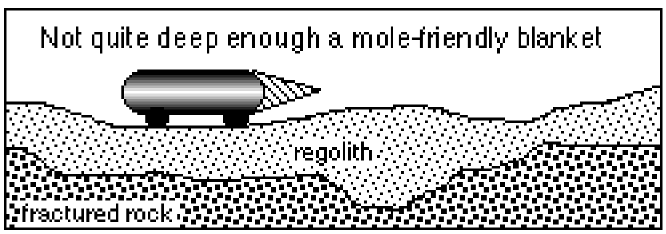
Off-road vehicles will not only ply trackless terrain but range far from convenient roadside flare sheds or automated self-help wayside service centers [“wayplexes”]. Short round trips can be ventured without provision for significant radiation shielding. But in times of Solar unrest especially, in Flare Season so to speak, off road vehicles must be prepared to “dig in” one way or the other.

This need is critical for remote construction site camps as well, whether engaged in building new outposts, mining operations, or road work. For the latter some sort of semi-permanent storm shelter would seem to be an immediate priority of setting up camp. Camp vehicles would normally park in an inter-docking array under the shelter. But here we are concerned rather with the situation for vehicles en route.

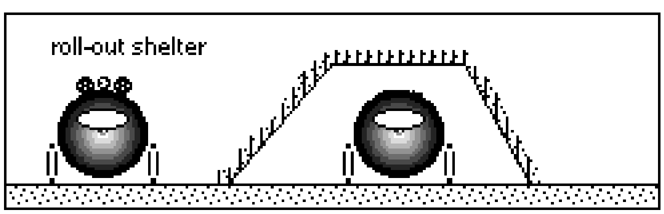


Circle of inter-docked camp vehicles under Shelter

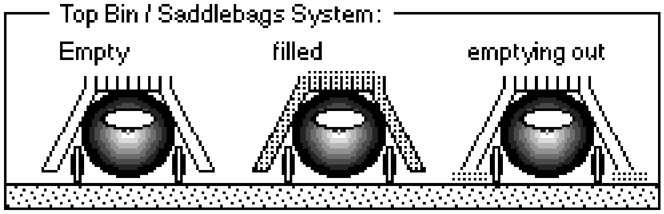
Copernicus Construction Company [CCC], the for-fun design and brainstorming activity group of LRS, has given some thought to how sudden shelter can be provided. One idea, coming straight out of a comic book read four or more decades ago, is to have a giant screw on one end of the vehicle so it can literally bore its way forward or backward into the powdery regolith. The problem here is that the regolith layer is in some places only a meter or two thick, not quite deep enough.



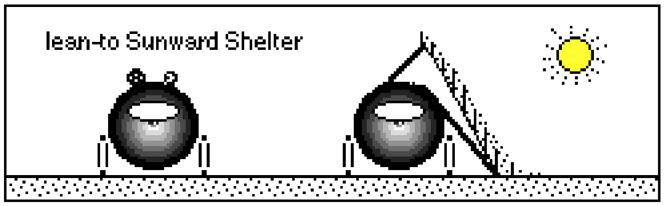
Another possibility is to carry along a collapsed, easily erectable space frame shelter and unrollable fiberglass canvas cover over which a scoop/conveyor system could blow regolith dust. Once deployed, such a shelter could be left in place permanently, its site marked on official maps for the convenience of others in the future. That leaves the vehicle, however, without protection if another storm should rise later at a point further along the route. Devising a way to “empty” the spaceframe/canvas shelter of its regolith overburden so that it can be packed up and stored on the vehicle rooftop or side for future use is an interesting engineering challenge.



Another system we thought of is a rooftop bin system with emptyable side mounted ‘saddlebags’. A scoop/conveyor could fill the bins and bags as needed. The need past, the bins and bags could be mechanically opened and the dust would pour out as the vehicle moved out of its parking spot.



Actually, in latitudes some distance north or south of the lunar equator, the problem becomes easier. All that's needed is a sloping shed facing Sunwards (the Sun creeps slowly across the lunar sky at only 1/28th the pace we are used to on Earth). A Solar Windbreak will be easier both to deploy and fill and to empty and and return to rooftop standby storage.



Even small open rover type buggies, should they venture much beyond the point of easy swift return will have to be equipped with some "KD" (easy erect, easy knockdown) system of flare storm protection. All vehicles of any kind, when parking at a site along the route for a few days would be advised to deploy their shelter system as a matter of prudence. In the meantime, even under calm Sun "weather", the voyagers will be at reduced accumulative exposure to the weaker but incessant cosmic rays coming from all sky vectors.

At the heart of the matter is the functional analogy between the protective high-pressure atmosphere of Earth and the regolith blanket which can serve as a condensed solidified atmosphere for the same protective purposes. **MMM**

MMM #109 - October 1997

[From the Article, "Luna City Streets"]

Role of the Settlement College/University

Any settlement institution of higher learning stands to play an enormous role in the development of the local culture and civilization and of the media and tools by which it is expressed. All this will be on display directly or indirectly on the streets. A university would assist on site companies in the development of new locally-produced building materials, appropriate architectural systems and construction methods. Its research may contribute to the appearance of new finish and decorative materials as well as an expansion of the available color palette. All this will affect the basic appearance of the pressurized street cylinder and its decoration.

University assistance in cottage industry formation will help speed the diversification of products available in streetside markets and shops; development of musical instruments fashionable from local building materials will have its affects on the sounds of the street; development of new plant hybrids will enrich and diversify landscaping options; the list goes on and on.

PROJECT "U-LUCY"
Founding the University of Luna in Cyberspace
An ISDC 1998 Mission Control™ Workshop

Milwaukee, WI, May 24, 1998 - By Peter Kokh

An enormous backlog of homework stands in the way of timely and efficient transition from a first beachhead outpost to economically viable lunar frontier town. We've learned a lot about the Moon during Apollo and since - but not nearly enough. If we don't want the Futuristry of the Moon to be one long "hurry up and wait" sad song, we must get serious about doing tons of groundwork. **Technologies must be ready as we need them**, not decades latter.

We need to know more about lunar-appropriate mining techniques and processing lunar regolith soils into all of the various elements we need - not just oxygen, silicon, and the four engineering metals; but also alloying ingredients. We need to know how to produce with the minimum of capital equipment, a workable suite of alloys, and other regolith-derived building materials: glass composites and "lunacrete", etc. The **chemical engineer** will be the unsung hero of the space frontier.

We need to learn how to fashion these into modular building elements so outpost-into-town expansion can rely as wholly as possible on local resources. We need to learn how to build all the various types of shelter we will need with minimum outdoor man hours. We need Moon-suited **architecture**, not just to design shells, but all the various working features and components as well: windows, sundows, airlocks and docks, and utility system components.

For those needed items, not all of whose parts can be made from elements feasible to produce on the Moon, we need an **Institute of Lunar Industrial Design** to design items to be easily be assembled on the Moon from minor lightweight components made on Earth and major heavier components "Made on Luna."

We also need a more thorough knowledge of the Moon itself, so various mining and manufacturing operations are sited to best advantage, so that our settlement sites are as ideal as they can be. We need the **Selenographers** and **Selenologists**.

We need to know what are the best off-Moon sites from which to source elements that can't be economically produced here. We need a very good **Economic Geography of the Solar System**.

We need a pool of expertise to assist the speedy diversification of products for both domestic and export markets. We need a school of **enterprise formation and product development.**

We need to develop a whole family of surface **vehicles**: coaches, trucks of all sorts, regolith movers and various other mobile construction and mining machines. But we also need to develop equipment and methods of landing imports on the Moon's surface and exporting value-added exports from it.

We need to learn how best to harness **solar power** on the Moon's surface, for domestic use and for export, using equipment largely locally made. We need to maximize **helium-3** extraction, to develop a suite of methods to store power produced in dayspan for **nightspan power** use. We need to figure out how to produce **nuclear fuels** on the Moon, to bypass the likely ban on export of such materials through the Earth's atmosphere. This is vital for the opening of Mars and the rest of the Outer Solar System.

Human Resources - Tanstaafl!

We need to learn to blend the work output of cheaper **manpower from Earth** with more expensive work that can only be done on site. Concepts such as telestaffing for routine administrative chores, and teletutoring need to be considered. Shadow crews on Earth can help find solutions to pressing on site problems in **simulation exercises.** Yeomen work can be done here and now to pioneer new Made-on-Luna building materials, art/craft media, and so on.

If we are to transition to actual settlement, ways to **minimize the onsite supervision** burden for **youth** and **seniors** must be developed. We must identify useful **chores and assignments** for them to free able adults for more productive work.

Some culturally significant matters also need attention: adoption of a Moon Calendar that pays attention to the lunar **dayspan-nightspan rhythms of the 'Sunth'**; testing appropriate **arts and crafts media**, and suitable performing art forms: **dance** and ballet; **sports** and games developed for sixthweight; adoption of unique frontier **holidays and festivities**.

Political institutions need attention. Stage by stage granting of home rule; interaction with international agencies on Earth, such as UNESCO, and the U.N. itself; a blueprint for a future federal lunar frontier republic; a reconsidered Bill of Rights; economic regimes to further timely development of lunar resources with due consideration for protecting global scenic and geological treasures, and maximizing the return for the local population.

Urgency of this Workload

A major fraction of this considerable workload does not have to wait until we have returned to the Moon with a token crew, let alone with a sizable pioneer population. Much work, at least much footwork, can be done by dedicated hard-working people on Earth, here and now, earning their honors as **"Ancestors of the Lunar Frontier."**

Founding "U-LuCy" Now!

Today the time is ripe. We have a marvelous new tool for organizing work and for publishing innovation: the cyberspace of the World Wide Web. What follows is a trial balloon proposal, to be sent to a number of Moon-interested organizations for feedstock, to set up and found The **University of Luna**, here and now on Earth for all the preliminary work that can be done now, in/on a **Cyberspace Campus**.

Interested parties are hereby invited to a very special and **historic ISDC '98 Workshop** to be tasked with agreeing upon the first concrete steps in **getting the U-LuCy Project up and running.**

Nature & Structure of U-LuCy

We propose U-LuCy exist on two levels:

- The **Undergraduate** level would develop **curricula** to **teach** current knowledge of the Moon and the steps and stages of how we might settle this new frontier.
- The **Graduate** level would be charged with advancing our knowledge and preparedness for the Lunar Frontier by soliciting and archiving masters level and doctoral **Student Theses** in the many areas needing attention.

Two other means at U-LuCy's disposal might be **design competitions** and assistance in developing **"spin-up" business plans** whereby a technology needed on the lunar frontier is developed now - for its various profitable terrestrial applications.

Money needed for website maintenance and construction fees, for stipends to overseeing faculty, and for publica-tion and promotion can be raised by a **"Friends of LuCy"** support organization, as well as from endowment solicitations, and various "spin-up" technology licensing fees and royalties.

We leave review of the above proposal and the working out of details, amendments, additions, etc. to the ISDC '98 U-LuCy Workshop. We ask input on whether or not the Workshop should be **two-tiered**, with a fee for active participants, no fee for silent auditors (notes can be passed to the Workshop Secretary) auditors. The workshop can have morning and afternoon, and if necessary, evening sessions.

Workshop Agenda

The agenda of the workshop is under development and open to constructive suggestions from any and all interested groups and individuals. The following is a starter list with no attempt at logical sequence or likely breakout into working groups.

- Capacity of Website needed (very large)
- Selection of a Web Server, Webmaster and crew
- Funds for maintaining the website
- Preliminary website structure
- “Departments” and “Schools” within U-LuCy
  See Appendix for Proposal
- Faculty, reporting protocols, nominal “salaries”
- Endowed Chairs
- Backup strategies for uncompleted tasks
- Publication of the Website
- Graduate level “recruitment”
- U-LuCy publications
- Intellectual Property of U-LuCy assisted developments of methodologies and technologies; Licenses, Royalties
- Initial Board of Directors – starter list
- Initial Board of Advisors – starter list
- Initial Board of Governors – starter list
- Corporate Sponsors and Endowments
- Cooperative MOUs with other Space interest organizations – Charter Memberships
- Cooperative MOUs with various leading space research Universities – Charter Memberships
- Cooperative MOUs with various Industrial companies and consortia – Charter Memberships
- Adaptation of the existing Space Research Matrix™ for keeping track of R&D work completed, work in progress, work needing (basic/additional) attention
- Initial timetable goals. Reports at successive ISDCs
- Use of the ISDC as venue for the U-LuCy and Friends of U-LuCy annual meetings
- Research Scholarships

An Open List of Invited Parties

(Charter Member Co-hosts)

- The Lunar Reclamation Society, Milwaukee
- Artemis Society International, Huntsville
- Lunar National Agricultural Experiment -LUNAX

(Charter Memberships Offered to:) (in alphabetical order)

- American Lunar Society, East Pittsburgh
- The Apollo Society (Delphi Project), Honolulu
- Biosphere II, Inc., Arizona
- Exitus, Inc. – Cuyahoga Valley SS, Cleveland
- Institute of Lunar Technology
- Institute for Teleoperation, Portland
- Lunar Enterprise Association
- Oregon L5 Society, Portland
- Oregon Moonbase, Portland/Bend
- Seattle Lunar Group Studies (SLuGS)
- Space Explorers, Inc. (Moonlink™), Green Bay
- Space Studies Institute, Princeton NJ
- Students for the Exploration & Development of Space/SEDS
- Other Moon-interested NSS Chapters

- Any and all other parties who would like to participate in thisn ISDC ‘98 Workshop

APPENDIX: University of Luna in Cyberspace
Proposed Schools & Departments [s]
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<u>SCHOOL OF SETTLEMENT TECHNOLOGY</u>

>> **Selenography & Selenology**

- viewpoint, needs different from IAU, independent
- Feature and Place Name REGISTRY
- ECONOMIC SELENOGRAPHY
  - Lavatube Teledetection PROGRAM
  - Astrobleme Teledetection PROGRAM
- Teleoperation, Telepresence, Buppets etc.

>> **Mining, Processing, Chemical Engineering**

- Element Production Suite Demonstration PROGRAM
- Glass, Ceramics, Cement, Metal Alloy Ingredients PROJECT
- Alloying & Coloring Agents Production PROJECT

>> **Consolar Resources Studies**

- Exo-sourcing
- export-import relationships
- exo-market development
- Comatose Comet Wildcatting PROGRAM

>> **Industrial Design and Manufacturing**

- Stowaway Resource Maximization
- Diversification Strategy and Timing
- MUS/cle DESIGN PROGRAM

>> **Plastic Arts and Crafts**

- Furniture, Furnishings and Decor Prototype
- Mare Manor PROJECT
- Craft finishable generic manufactures
- Lunar-appropriate media development

>> **Biospherics, Agriculture, & Horticulture**

- Modular Biospherics
- recycling system and strategy development
- environmental attention
- Food Production
- Fiber Production
- Pharmaceuticals

>> **Architecture, Infrastructure, Urban Plans**

- Incl. construction, remodeling, and expansion
- Modular Element Testbed Assembly PROGRAM
  - Visual/Solar Access, Utility components, Ramadas, Panorama Domes etc.

>> **Transportation technology**

- Mass Driver Program
- Harenobraking Program
- Road Construction and facilities
- LunaR Fuels and Engines PROGRAM

- Dust Engine PROGRAM
- Lunar skimmer PROGRAM
- Tourist arrangements, destinations, facilities plan

>> **Energy Generation and Nightspan Storage**
- He3 extraction, Lunar Solar Power Arrays
- Nightspan Storage, nuclear fuels

>> **Astronomy and S.E.T.I.**
- Farside radio astronomy
- Optical astronomy program
- Lunar Amateur Astronomy Extension

>> **Enterprise Formation and Assistance**
- Terrestrial opportunities – Spin-up tech PROGRAM
- Domestic Lunar needs
- Export opportunities and market development
- Solar system trade economics

<u>**SCHOOL OF PIONEER RESOURCES**</u>

>> **Earthside Telestaff Project**
- Recruit Homework & simulations Program
- Junior, Senior Productivity Program
- Teletutoring
- Friends of U-LuCy Outreach Extension PROGRAM
- Traveling Annual Settler Training CAMPS

>> **Human Resource Utilization**
- Junior, Senior, Gene Pool expansion programs

>> **Space Frontier Culture**
- Tanstaafl and human resource utilization
  - settler youth, universal service, seniors
- dayspan/nightspan/sunth and Calendar
- plastic/performing arts
  - Simulated Lunar-appropriate plastic arts (paint, sculpture, ceramics, etc.)
  - Performing Arts
    + Sports development simulations PROJECT
    + Lunar dance and ballet simulations
  - Posthumous & contemporary Honors AWARDS

<u>**SCHOOL OF LUNAR FRONTIER POLITICAL SCIENCE**</u>

>> **Interior Affairs**
- Lunar Federalization
- surface turf allotment, global subdivision
- settlement hinterlands
- province hinterlands
- national, scenic, selenologic, resource Preserves
- subdivision charter requirements
- Lease Terms (terrestrial R&D, Science concerns)
  - (free if equipment, organic waste left behind in usable condition)
- Manufacturing, Resource Removal licensing STUDY
- Scenic / Selenographic easements requirements

>> **Frontier Republic Charter & Constitution**
- Conditions, stages of autonomy and home rule
- Bill of Rights

• Executive
• Legislative
• Judicial
• Internal Security
• External Security

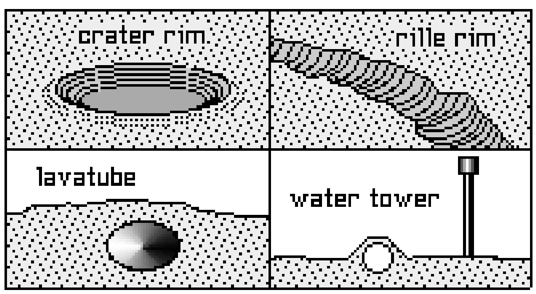
>> **Earth Political, Economic, Cultural, Relations**

• UNESCO, WHO, affiliation, interaction, interfacing with other international agencies
• Urban Tropics Energy Market Affiliation STUDY

To comment on any of the above, offer assistance, request participation in the workshop, and for other inputs and requests: KokhMMM@aol.com

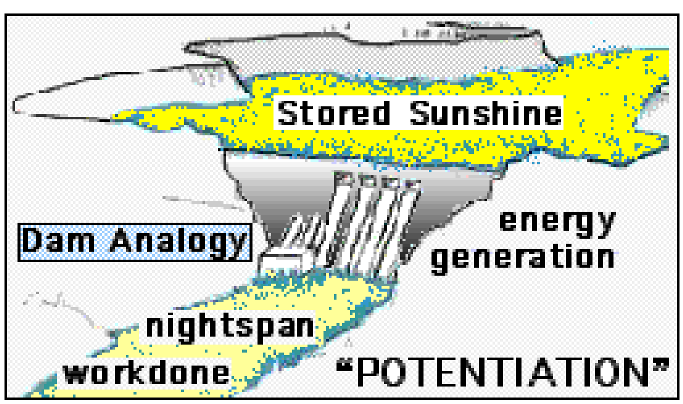
[**NOTE:** Not enough of the people with the needed mix of expertise and talent attended this workshop to carry the project any farther. It would languish until 2007, when together with new Moon Society Director of Project Development, we built a website and outreach materials for a presentation at ISDC 2007 in Dallas, Texas. We had renamed it "**The University of Luna Project**" – http://www.moonsociety.org/university/]

MMM #126 – June 1999



"Heads" for Recirculating Hydroelectric Systems

At right, we see four situations in which there is a high enough "head" even in low lunar gravity, to install a capable "hydroelectric" system on the Moon. Prudently ample water reserves would be pumped to an upper reservoir by solar power during dayspan, then purified by solar ultraviolet under quartz panes. After nightfall, it would be allowed to fall downslope to turbine generators. Details, extras and other ideas for nightspan power: See the article "Potentiation" just below.



“Potentiation”

A Strategy for Getting through the Nightspan on the Moon’s Own Terms

By Peter Kokh [Presented at ISDC 1999, Houston]

Taking Back the Nightspan

On Earth, in many urban areas, there is one special night given over to the assertion of everyone’s right to be out and about, safely, at night. “Take back the Night” is aimed at programs that neutralize or reduce nighttime crime and violence that in some areas has frightened people into remaining imprisoned in their homes between sundown and sunup the morning after.

On the Moon, the nightspan is 14.75 days long, 30 times as long as an average terrestrial night. Sunshine is the principal readily tappable local source of energy on the Moon. Its unavailability during nightspan makes the Moon a forbidding place to many people.

If you are one of these, you may need to take a serious look at your pioneer spirit quotient [PSQ]. In every one of the frontiers of the past, pioneers found themselves challenged by the unavailability of various things they had taken for granted in their native homelands. Those who survived, did so by turning to their inner resourcefulness; they “found” ways, not just to make do, but to thrive under. This inventiveness, this eagerness to take on challenges, seems disturbingly lacking in many space-interested people today, the very segment of the population one would expect to be most ready to imagineer their way around every obstacle.

Some of these “discouragees” would rely on nuclear power alone. But if there is a nuclear power plant anywhere on Earth without either planned or unplanned downtime or both, we haven’t heard of it. Nuclear is fine – but it can’t be relied upon 100% and prudent settlers will have backup power generation capacity. To the extent it will serve genuine settlement, not just a token Kilroy outpost, nuclear has to be “Lunar Nuclear.” But more on that later.

Other discouragees just give up and would restrict themselves to a couple of tiny sites at both lunar poles where it is “purported” that “sunlight,” always more or less tangential to the surface, is available month around. In fact, the “Peak of Eternal Light” at the south lunar pole enjoys sunlight only 86% of the time with several dark periods. All such spots are inevitably mountain peaks or crater rims, not exactly prime turf upon which to land or erect a base for routine operations.

**Some are so intimidated by the lunar nightspan,
that they would bypass the Moon altogether
in Human expansion into the Solar System.**

What we have to say is meant instead for those of you who welcome the challenge of the nightspan. Fully 99.99% of the Moon’s surface outside the permashade areas in polar craters experiences alternating two week long dayspans and equally long nightspans. If we are going to “do the Moon.” this is the Moon we need to do.

We will not earn the right to say we have a permanent human presence on the Moon until we have learned how to deal with the Moon on its own terms. We have to take back the night, the lunar nightspan from the dread bogeyman of the energy desert that tests us. Lunan pioneers with the right stuff will learn not to fear the night, but to love it and cherish is as an equal movement in life’s rhythms.

Potential Energy Reservoirs

Potential energy is the reserve energy an object has by virtue of its position in an energy gradient. There are several kinds of “energy hills.” All kinds of potential energy reservoirs available on Earth are also available on the Moon. It is up to us to build these various reservoirs, and fill them.

This deliberate effort we dub “potentiation.” Potentiation will not only make energy available for the nightspan, it will take energy to put in place. The unlimited solar energy available everywhere on the Moon outside permashaded polar craters is tappable to do the job.

The dayspan holds all the keys to the nightspan. But we have to do the right things during dayspan to make our plan work. We have to not only use available solar energy, we must produce a surplus, and store it "uphill." The endless broad and deep river of sunshine can be dammed up. The dams can take various forms of "uphill" holding reservoirs: gravitational, thermal, chemical, angular momentum, and radioactive.

Gravity Slopes & Hydroelectric Power

Gravity hills, slopes, gradients, wells: something is placed at the top of a slope, poised to create energy by being allowed to fall. On Earth, we dam up rivers at convenient constricting points. This creates a "head." Water is allowed to spill over the dam in a controlled fashion, gathering momentum from its plunge, and using this momentum to spin turbines that run electric power generators.

No rivers on the Moon? No problem! Wherever we place our outposts and settlements, we will need appreciable amounts of water: as an essential component of whatever mini-biospheres we establish to reencradle ourselves; for food production; for drinking, washing, and hygiene; for use as recyclable reagents and handling media in industry. We will need a substantial water surplus, in part consisting of water being recycled and purified.

During dayspan, solar energy can be used to pump the water surplus uphill: nearby crater rims, rille shoulders, or the surface above lavatubes. At night this water is returned to the loop through tubes plunging to turbine generators downslope.

Of course, the amount of water available for this form of nightspan energy generation depends on the generosity of the settlement's water endowment. Now that Lunar Prospector has confirmed the discovery of substantial water ice reserves at both lunar poles, this idea is not far-fetched.

What about the low lunar gravity? Won't that work against the idea? Well, Niagara Falls, which produces a lot of power, has a head of about 150 feet. To match that head, we'd have to have a reservoir 6 times as high above the generator turbines, or 900 feet up. Some Crater rims are 10,000 feet or more above the crater floors. Many mare coastal sites are near high rampart mountains. These sites are advantaged by access to both major suites of regolith materials (highland soils rich in aluminum, calcium, and magnesium, and mare soils enriched in iron and titanium). Even mid-mare sites that involve the use of lavatubes will come with ready "heads" of several hundred meters between the exposed surface and the floor of the tube underneath. Nor is a Niagara-equivalent head needed. There are many working low-head hydroelectric sites around the country in the 20 foot range. Where there are no natural "heads" for reservoir placement, we can simply build water towers hundreds of feet high, using dayspan solar to pump them full.

Now let's play with this idea. Dayspan sunshine can also be used to purify and treat the water in the reservoir - if the reservoir is covered with ultraviolet transparent quartz (pure silicon dioxide glass). Going a step further, dayspan sunshine can be used to electrolyze this stored treated water into oxygen and hydrogen. After nightfall, the hydrogen and oxygen can be recombined in a bank of fuel cells, producing both energy on the spot plus the water to fall downhill to the generator turbines, to produce yet more energy. All these processes would have to be paced to extend this potential energy resource through the long nightspan.

Lunar Hydroelectric as sketched above, is the brainchild of Myles A. Mullikin, Milwaukee Lunar Reclamation Society co-founder. It was one of several of his major contributions to our "Prinzton" runner up entry in NSS's Space Habitat Design Competition during the winter of 1988-'89. Hydroelectric power on the Moon is the last thing that occurs to most people mulling the problem. But it turns out to be very realistic for any kind of outpost or settlement. No one pretends the amount of energy stored during dayspan and produced during nightspan by a hydroelectric scheme will meet all the settlement's power needs. But it is one workable component of a mix pioneers will have up their sleeves. Planners should consider incorporating such interactive water storage into the settlement utility system.

Chemical Energy Stores

If we can use available dayspan solar power to reduce chemical substances into fuels that we can oxidize at night, this would be another way of storing surplus dayspan sunshine. And an especially convenient way at that, for such fuels can run not only static generators, but mobile engines in vehicles.

The polar water ice reserves are, by common expectation, derived from comet volatiles, reaching the Moon by impact, and migrating during the safety of nightspan (in the lee of the dispersing solar wind) to the permanent safety of permanently shaded polar cold traps. Now comets include large amounts of volatiles other than water. Carbon oxide and nitrogen oxide ices are a major component. We can hope that some of these volatiles will have reached the safety of the polar permashade fields and be found intermixed in the water-ice. The Lunar Prospector team has characterized the polar water ice as relatively pure. But this is with respect to mixed in regolith, not necessarily with respect to other volatiles.

Now the pioneers will need lots of water. But 89% of water by weight is oxygen. As Oxygen makes up 46% of lunar soils by weight, what the pioneers will really need is the polar hydrogen. Shipping water with megatons of included oxygen to settlement sites will be like shipping coals to Newcastle, or ice to Alaska. On the other hand, hydrogen is relatively hard to handle and ship as either liquid or gas.

If the polar reserves include carbon monoxide or carbon dioxide ices, available solar power could be used to refine these ices, reducing them chemically to methane, $CH4$. Shipped or piped as either liquid or gas, both the hydrogen and carbon will be most welcome. And combining them with local oxygen (produced from the soil by solar power on site) in fuel cells during the nightspan to produce water, carbon dioxide for the biosphere, and water. The portion of methane arriving during dayspan could accumulate in storage tanks until nightfall. In this way, dayspan sunshine both at the poles and on site is used to produce nightspan-usable fuel and power.

Additionally, methane can be produced in the settlement from composted waste biomass., and used as a fuel for motor engines or generators, producing power, water vapor, and carbon dioxide, a necessary component of the settlement atmosphere. “Biogenic” methane will be an important ingredient in making the settlement biosphere work - why not also use it to help the settlement through the nightspan?

Electrolysis of on hand water reserves using surplus dayspan sunshine is another way to accumulate and store fuel for nightspan use, namely, oxygen and hydrogen to burn in fuel cells, as we’ve already mentioned. In short, we need to take the dayspan opportunities out there to charge various types of chemical batteries for nightspan use. This is the simple pioneer virtue of “energy husbandry.”

Angular Momentum “slopes”

Large flywheels made of lunar materials, metal alloys or composites, could be placed in small-sized crater bowls for safety. The crater rim slopes would catch any shrapnel if the flywheel’s angular momentum exceeded its cohesive strength and disintegrated. Flywheels could also be placed in lavatube voids. During the dayspan, solar electric power could be used to rev up the flywheel. An expandable modular bank of smaller units would combine safety and the ability to store whatever amount of power might be needed.

Thermal slopes & Magma Pools

The Moon is dead geologically speaking. So “geothermal” or selenothermal power is out of the question, right? Not for those with imagination! If there is an early cast basalt industry to provide paving blocks and other low performance items of use to the expanding base, possibly as a sideline to oxygen production through heating the moon rock, the excess residual pool of molten regolith produced during the dayspan can be stored in subsurface voids as pools of magma, shielded from the heat-sucking night sky. These holding reservoirs could be lined with refractory materials made on the Moon. The poor thermal conductivity of the regolith overburden will work to conserve the magma pool’s heat. How much energy do you need to get through the nightspan? Just melt and store that much regolith as molten magma. This is the vision of Lunar Reclamation Society member-at-large David A. Dunlop, of Green Bay, Wisconsin.

As highland regolith generally has a higher melting point than mare regolith, highland regolith can be melted and cast to form a refractory container for mare magma. As we progress further in extracting purified elements, we can improve on this by casting refractory elements out of aluminum oxide.

This regolith melting operation need not be undertaken solely for the purpose of providing a high heat reservoir to tap for nightspan energy. Fused and cast regolith products, specifically cast mare basalt, could provide a whole suite of useful products in the early settlement era, products where high performance is not a requirement: floor and paving tiles and slabs, tableware (dishes), table tops, other furniture items, pots large and small to be used as planter beds, other artifacts, etc.

Cast basalt as a building material and manufacturing stuff may seem exotic. But in fact, there has been a cast basalt industry in central Europe for ages. We need to become familiar with this precedent and take it further, so that when we return to the Moon, we can hit the ground running. Oregon and Hawaii would be good places to practice.

Nader Khalili of the Geltaften Foundation has developed a detailed proposal for casting shelter modules. Casting into a spinning mold would be one simple method of forming conical and hemispheric shapes. Adding crude glass fibers made from highland regolith to the magma mix would provide considerable strength to the finished product.

Magma heat can be used to melt and cast materials with lower melting points, to bend and temper alloys, to glaze ceramics, to crack complex compounds into simpler chemical components, and so on. If this manufacturing activity continued right up to sunset, a leftover magma pool would remain, ready to be used to produce steam to run generators.

There should also be a way to tap the residual heat of recent castings still in the kiln. As magma and castings would slowly cool, it'd seem reasonable to use up the magma heat for electrical generation first, phasing in hydroelectric and fuel cells as the magma pool cooled below the point of usefulness.

Further, magma-generated steam can do more than run generators. Steam can transport heat for baking and curing and heating. Steam can run air compressors and ventilators. Steam can pump water. Steam was once king. Now it is largely forgotten. Lunar pioneers would do well to take a second look.

Mark Reiff suggests another form of lunar heat pump. If vibro-accoustic testing locates a relatively small underground void (cavern) near the surface (less than 100 feet), this void can be accessed by drilling. The natural reservoir can then be filled with a thermally conductive material (e.g. smelting regolith into molten aluminum). The thermal properties of the available material should drive the purity requirements. The material would be allowed to reach equilibrium (cool).

Next you would set up a thermal dynamic generator (Sterling cycle would work good) with your heat source on one end and the newly created heat sink connected to the other. You could shade the generator and the top of the heat sink to even provide power by dayspan too. [Smelting aluminum, however, is not likely to be an early outpost technology – Ed.]

Modular Home Solar

At ISDC '98, we spoke of a modular approach to biospherics, designing every lunar habitat and function space to pretreat human wastes generated therein. If we consider that a lunar settlement is not something that will be built all at once, but which may grow and grow, a similar modular approach to providing needed electrical power generation seems appropriate as well.

To some extent it may be possible to do this habitat by habitat for surface settlement structures where dayspan sunshine is available just above the shielding overburden. For lavatube settlements, however, this home-by-home contribution would not seem feasible. In surface settlement complexes, individual habitats could have solar panels above, designed to catch the sun's rays from the changing angle through the dayspan. This could be either a first or complimentary source of power, reducing the amount that had to be provided by the common settlement grid, and taking the edge off the settlement's growing pains. Such an approach also distributes vulnerability.

We need to seek for practical ways individual habitats could store, and later tap, excess or surplus solar power for nightspan use. On Earth, The Mother Earth News has long taken the lead in helping individual homesteaders to become increasingly self-sufficient and self-reliant. The TMEN spirit provides an invaluable inspiration for future lunar pioneers. Most TMEN-illustrated "appropriate technologies" will not be directly translatable to lunar situations. But the spirit needs to be copied. Hopefully, a Mother Moon News will lead the way in this regard. Indeed, in our own personal dreams, we live long enough to graduate from being editor of **Moon Miners' Manifesto** to becoming editor of **The Mother Moon News**.

"Working Smart" - Operations Engineering

We need to provide electrical power for these night-span activities: production, work in general, daily living, and recreation. No matter what mix of power generation sources we use for this purpose, and whether or not a nuclear power plant is available as a major part of this mix, there is no escaping the fact that there will always be more power available during dayspan than nightspan. Why? Because day-span has available unlimited solar power in addition.

It is unbelievably naive then, to try to plan a lunar economy in which the very same mix of tasks is performed dayspan and nightspan alike without any difference. Here on Earth we are spoiled. We want to do what we want to do when we feel like doing it. Hopefully, the lunar pioneers for whom we are paving the way will be a little smarter, and a lot wiser. Lunans will need to "work smart", going through the task load at a pace that goes with the grain of the host environment.

This means a simple rhythm that divides the task load, industry by industry, occupation by occupation - wherever practical - into one set of more energy-intensive tasks to be accomplished during dayspan, and a second complementary set of energy-light, perhaps more manpower-intensive tasks to be gone through during nightspan.

Lunans will do more production work during the dayspan, more maintenance, inventory, packaging, and shipping work during nightspan - again, to the extent feasible. Even here on Earth, some electric utility companies use a two-tiered rate structure to encourage their customers to voluntarily postpone some high-load activities to non-peak usage hours.

On the Moon we are talking about the same thing, on a monthly rather than daily basis, and on a much more extensive scale. It is reasonable that on the Moon electric power to industrial consumers will be priced much higher during nightspan to encourage this type of cooperation. The whole lunar economy will operate as some giant alternator, or as a set of lungs that inhale and exhale.

For manufacturers and others, this means adopting a whole new Philosophy of Operations. It means hiring Operations Managers who are enthused supporters of the new modus operandi, rather than those who resist it kicking and screaming.

For workers and others, this task-sorted, polarized operational scheduling will provide a fortnightly change of pace. On the Moon, where there is no changing weather, not even any changing seasons to provide some welcome freshness to life, this bimonthly change of work rhythm will be a psychological bonanza. Those who would insist on running their operations as if dayspan and nightspan made no difference, will find their employees to have lower morale and a greater incidence of psychological and personal problems in comparison.

If some industries have an imbalance, either a preponderance of energy intensive or energy light tasks, they might trade some workers. An energy-intensive casting operation may transfer many of its employees to a sister operation in some industry that has an excess of manpower-intensive, energy light tasks. Such bimonthly change of pace switches might be a much-loved perk for the people involved. Variety is the spice of life. Predictable changes of pace can be salutary and welcome.

It is likely that the load of production and export oriented tasks will still be lower in terms of man-hour needs during nightspan than dayspan. So the two nightspan work weeks could be shorter, either in work hours per day, or in work days per week, or with more generous flextime rules.

Surplus free time could be used for hobbies and/or building up individual cottage industries. Thus the lunar nightspan could be the principal generator of new private enterprises, a wellspring of lunar industrial and economic diversification and continued growth. The domestic economy would be the first beneficiary, but it is inconceivable that new export lines would not emerge from such enterprise.

If this nightspan power "deficit" were ever to be effectively eliminated, the biggest source of rhythm and change of pace would be gone with it. Productivity gains would be temporary as morale slowly plummeted from routine, boredom, ennui.

It's all about learning to live on the Moon, on the Moon's own terms. On Luna, do as the Lunans do! On Earth we have many examples in Nature of plants and animals who have seasonal changing rhythms: squirrels, birds, bears, the list goes on and on. Their daily rhythms adjust to sometimes drastic changes in the environment.

Another analogy is offered in the extreme in bimorphic biological economies, demonstrated by the primitive Hydra, a minute aquatic animal that exists in two quite different alternating generations, the polyp, and the medusa. Similarly, on the Moon, the dayspan economic activity will lead into the nightspan economy which will prepare for the next dayspan and so on indefinitely – two bimorphic generations of one and the same economy.

Lunar Appropriate Nuclear Power

If nuclear power is to be a major player on the Moon, we have to look beyond the dawn period in which ready-to-run nuclear plants are imported from Earth. That's fine for a limited dead-end Antarctic style small outpost, which is not expected to grow in its energy requirements. We are not among those inspired by, or envious of the Antarctic achievements. Instead we foresee a continually growing Indus-trial and civilian settlement network on the Moon. And so we look beyond such seemingly lead-nowhere options to a uniquely "lunar-appropriate nuclear power industry." Such an industry would incor-porate these features.

(1)The lunar nuclear power plant should burn nuclear fuels produced on the Moon as

a) export of nuclear fuel through Earth's atmosphere may be embargoed by the political successes of those environmental extremists who even now oppose RTG-powered spacecraft to the outer Solar System. And

b) even if this scenario should be successfully avoided, reliance on politically fickle regimes on Earth for sourcing absolutely critical needs, such as nuclear fuels, would mean perpetuating blackmail-inviting dependence upon Earth on the part of settlers.

Lunar Prospector has mapped major Thorium reserves on the Moon. Thorium can be transmuted in lunar fast breeder reactors into fissionable Uranium 233. [see MMM # 123 March '99, pp. 6-7 "Lunar Thorium: Key to Opening up Mars", and MMM #116 July '98, pp. 7-8 "Uranium & Thorium on the Moon"] Thorium can thus power industrial expansion on the Moon, as well as fuel nuclear ships on the Mars run, without which it is not reasonable to expect the Mars Frontier will ever be opened to settlement.

(2) Nuclear plant engineers and architects need to follow the "**MUS/cle**" paradigm in which the more **M**assive, **U**nitary, **S**imple components are manufactured on the Moon, and only the more sophisticated **c**omplex, **l**ightweight, and **e**lectronic "works" subassemblies are manufactured on Earth. This division of manufacturing labor will work to keep total imported mass low and maximize the lunar contribution for best overall affordability – all while building lunar industrial muscle. All Moon-based industries need to follow this paradigm if the lunar economy is to run in the black.

(3) A standard small "gangable" nuclear plant module must be the goal of this joint MUS/cle design and development process. The modules need to be relatively inexpensive, and manufacturable on demand in quick order, "cle" part on Earth, "MUS" part on the Moon. They need to be functionally gang-able into multiple module plants to fit the growing energy demands of quickly expanding settlements as well as small static outposts.

The Moon does have an abundant supply of Helium-3, the ideal fusion fuel. But fusion power has yet to be demonstrated as an engineerable reality.

Other nightspan power solutions frequently proposed are well down the road, something for later generation advanced settlements to consider. These include solar power satellites (the only viable locations not requiring station keeping fuel are L4 and L5 ten times as far from the lunar surface as GEO is from Earth), lunar solar array networks (one over the nearest pole makes the most sense as it would be in sunlight whenever the base is in darkness), and lunar super-conducting power storage rings (the prognosis is not good for finding a material producible on the Moon that is superconducting at the temperature of liquid oxygen, the lunar source-able coolant of choice).

A Tale of Two Cities

Those for whom everything old is worthless, and only the new deserves consideration, and those without patience for the inconvenience of having to rethink operations to reschedule them as paired sets of energy-intensive and energy-light tasks that can be performed sequentially, will champion an all nuclear Moon. Let them enjoy their horse blinders.

If we could imagine two identical starter settlements, both in equally favorable sites for local resource-based indus-trial expansion, but one all nuclear, the other with a healthy reliance on dayspan solar for potentiating nightspan power needs in addition to a nuclear base load, it should be clear that if we revisit them twenty years down the road, it will be no contest which settlement will have grown the most both in population and economic diversity and prosperity.

We need to take a holistic approach to solving energy problems on the Moon. The Moon is a place where we can do precious little as we have been used to doing things on Earth. The Moon is a place where we will be challenged to the utmost in many ways. To be equal to the challenge, we have to examine all the options and hedge all our bets. And, we have to embrace life on the Moon on the Moon's own terms.

As we have taken pains to point out, most of these proposed alternative nightspan energy sources mesh well with the industrial and/or biosphere maintenance needs and goals of the settlement. Even if we have adequate power from a nuke - adequate for the time being anyway - it would be plain stupid not to develop the water reserve-fuel cell cycle, the magma pool-cast basalt cycle, and the methane engine fuel cycles. A settlement that opted not to do so, would court failure.

Conclusion - The Habit of "Energy Husbandry"

In short, if we are going to "do the Moon" we must engage the Moon on its own terms: we have to bite the bullet of dealing with the lunar nightspan head on. Unfortunately, biting the bullet is not a virtue of the predominant space culture. On another issue, writers and visionaries may talk all they want about artificial gravity for space stations and for space vehicles on long journeys. But in industry and agency alike, this is an "unmentionable" by "unspoken" agreement. NASA is in the zero-G rut, comfortable to the point of addiction, deaf and blind to reasons to go beyond this cozy nest.

That is one vector of space that the powers that be have no wish to explore. The lunar nightspan is another such vector. We avoided it totally in the Apollo Program - all our landing excursions took place entirely in the local lunar mid-morning timeframe. As NASA does not allow itself to look beyond a limited crew lunar outpost, the idea of a growing flexible power demand can be conveniently pushed back into the nearest closet.

For those of us who have greater dreams, it is absolutely vital that we hitch them to a less tired old horse. We are given, on the Moon, a highly polarized environment. We need to learn how to dam up this overabundant dayspan sunshine so we can tap this reservoir for productive activities all nightspan long. Only then can we boast that "we have arrived" on the Moon, that our presence is "permanent", that we have truly become the adoptive children of this raw unforgiving world, that we have become "Lunans."

Lunans will "husband energy", and learn to mine "energy tailings." In doing so religiously, they will empower themselves not just to "get through" the nightspan, but to producing a "second harvest" from the dayspan sunshine in the process. In time, to Lunans it will have become quite clear that the long nightspan is an asset, not at all the dread liability that today dispirits many. Those who need Earthlike conditions and settings will have to wait a long time before the space economy generates enough wealth to produce them artificially. Meanwhile, pioneers with the right stuff will be ready. **MMM**

MMM #130 - November 1999

Radar Flashbulbs on the Moon

The Lunar Lavatube Locator Program

By Tom Billings, Project Head

Abstract - This proposal by the Lunar Base Research Team of the Oregon L5 Society is organized, in Schedule and Budget, as a modular program, to bring use of the technology of ground-penetrating radar in incremental steps for exploring the Solar System, to the attention of the research and industrial communities.

It funds a 12 month effort to establish this innovative ground-penetrating radar program. The product will be **a Discovery-class mission proposal**, which will focus on confirming the location of valuable lunar lavatube sites for use as lunar base sites.

Presentations to researchers throughout the twelve months will also bring forward the further use of this technology at asteroids and other bodies lacking substantial liquid water. Use of the technology for examining other subsurface structures and resources will be brought forwards as far as theory will allow, considering the lack of subsurface empirical data from such bodies at present.

The Program Vision

Lavatube caves under the lunar surface will be very useful as lunar base sites. They have left surface indicators that can be found in computerized searches of the Clementine data. A large portion of the targeting data for this program will be acquired by a computer search of the Clementine Lunar Probe's database. Software and hardware for this computer search are now being integrated by volunteers from the Lunar Base Research Team of the Oregon L5 Society and from Lewis & Clark College, and Pacific University, in Oregon. The software was donated by JPL and the Sun Sparc Stations were donated by Mitron Corp. Hardware and software integration assistance is provided by Sun Microsystems.

Lavatube sites that are located should be investigated before commitment to a lunar base there. Ground-penetrating radar images of actual voids at particular sites seem the next step, if images can be obtained cheaply. This proposal describes a program that brings to the research community a combination of technologies to obtain such images of lavatube caves at low incremental cost.

As early as the Apollo Lunar Sounder Experiment, radar has penetrated the Moon to substantial depths. Only soundings were possible given the combination of penetrating wavelengths (1-20 meters) and the aperture of any antenna that could be carried by the Apollo Service Module.

How it would work

Now, operation of the Very Long Baseline Array (VLBA) by NRAO provides a radar aperture that, even from the Earth, could provide a resolution of 20-200 meters at the lunar surface with wavelengths of .5-5.0 meters on the lunar Nearside. Lavatube surface indicators have been found in Apollo photos for caves up to 1100 meters across. But where is the radar energy reflecting off the walls of these lavatube voids to come from?

The 4th power range coefficient in the denominator of the Radar Equation makes this extremely costly if the rf source is on Earth. Likewise, transport to lunar orbit of a powerful rf source is beyond any present budgetary reality. However, if we are investigating only the immediate areas around sites found by the Clementine data search, then a very localized rf source, of appropriate power and wavelength, becomes useful. Such a localized source would give a signal/noise ratio governed by a 2nd power range coefficient in the Radar Equation. This factor, combined with the resolution of the VLBA may make a cheap mission possible.

We would propose that unconventional rf sources can be placed close to some lavatube sites located by lunar surface indicators for far less than an orbiting rf source would cost.

A free falling object launched from Earth would posses much kinetic energy at the lunar surface. Converting a large portion of that kinetic energy to rf energy is possible with a two-part probe structured as 2 extended concentric metal cylinders that slide past each other when the forward cylinder's end strikes the lunar surface. By allowing a strong magnetic field to brake the rear cylinder's motion, very large electrical currents can be generated in the second cylinder. These large currents would have to be conditioned and turned into appropriate wavelength rf energy, then radiated into the local lunar surface very rapidly.

It is also possible to attain conversion from mechanical to electrical energy by compressing electrostatic fields in large capacitors, instead of magnetic fields. Both techniques should be explored in the project.

At a 2.35 km/sec. impact speed, the probe would have less than 1/2000th of a second to "flash" the lunar surface with rf energy before the transmitter and power conditioners at the back of the probe smash into the surface themselves. If it can "flash" successfully, then the rf energy can penetrate the dry lunar surface, reflecting off large discontinuities within the lunar material, including the voids of lavatube caves in the local area.

That rf signal would bounce back to Earth and be picked up by the receivers of the VLBA. Processing of the received signal should allow us to discern which local sites do in fact have lavatube caverns, and characteristics such as overburden, width, depth and length. Presence of local ice and other desirable characteristics might be determined by more sophisticated analysis.

Lunar Mission Options

The mass of the probe will be determined by the energy requirements for penetration at a given wavelength and for reception at the VLBA (Very Long Baseline Array), as well as the total efficiency of conversion from kinetic energy to rf energy. Each probe's "flash" may be able to illuminate strata for a few hundred to a few thousand meters around the probe impact site. This may allow several voids to be confirmed, or even newly found, from one probe. The observation time for the VLBA will be short enough to not intrude much on the normal VLBA observation schedule. This should allow small enough "flashbulb" probes to be sent along with other lunar missions on a "mass-budget available" basis.

If a special lunar mission is set aside for these probes, then timing of individual impacts might be made provisional by selecting a figure-8 trajectory passing close to both Earth and Moon that would return the spacecraft "bus" to a release window once each lunar orbit. Kicking the next small probe out at a slightly different time, with a slightly different push during that window could change the impact point on the Moon and allow a wide range of sites on the Moon to be sampled by these probes. If there is sufficient excess capability available on a commercial comsat launch, then a small package with its own booster might "piggyback" to

GTO (Geostationary Transfer Orbit). From there the delta-v requirements for lunar impact are much reduced. Multiple launch opportunities might be available over some years for a continuing program of exploration with this basic flight concept.

For targets away from the easiest Nearside opportunities, several other sensor options become available with more investment in sensor systems. Small free-flying arrays of radar sensors are being proposed for a number of missions, by researchers at both Sandia and Los Alamos. An array of 20 sensor satellites, each massing 15 kg could become available in lunar orbit through the results of recent projects looking at satellite sensor arrays at Sandia and elsewhere. At an altitude of 100 kilometers, an array with a diameter of 10 km. could give a resolution of about 6 meters, with a wavelength of 0.5 meters.

This would require that impact at the surface will happen when the array is overhead in good position over that particular site. The orbital mechanics of trajectories for impact on the leading limb of the Moon will be easier than any other, but all areas should be reachable. This may dictate that the "bus" for the flashbulbs be placed in highly eccentric lunar orbit, as well as requiring a deorbit thruster to bring each flashbulb to an impact trajectory. Analysis of these orbital trajectories will be begun during this startup of the program.

Other Targets for this technology

This technique may also be applicable to most dry targets in the solar system which have subsurface structures of interest to investigators or investors. Mercury and the moons of Mars are obvious candidates, as is Mars itself, as well as a number of other rocky satellites in the outer solar system.

For single targets, there are even smaller sensors being developed in programs like those at Los Alamos. 15 gram sensors that can sense and report the reception of specific burst of radar wavelengths would be spread in an array about 100 km. behind the flashbulb as it falls into the surface. As the reflected burst of rf energy is sensed, each sensor in the array provides both time and amplitude info on appropriate frequencies to a "bus" that dispensed the sensors and tracked their positions. This "bus" then transmits the information back to Earth before the array follows the flashbulb to impact.

An important further application of this technology is in radar penetration of asteroid bodies farther from Earth. These will not be large enough to justify the deployment of a full orbiting array of 15Kg sensor satellites. They would be very interesting for smaller investments, expending only a 10 Kg flashbulb and a 10 Kg "bus" and microsensor array. This would allow structural characteristics of asteroids with non-conductive interiors to be probed, and conductive metallic asteroids to be identified in a definite fashion, at a much lower cost than a rendezvous and landing mission would require.

In speaking to members of the lunar research community, we have found that little effort has been put into lunar ground-penetrating radar in the last 25 years. Unfamiliarity has contributed to doubts. While some have been skeptical about the concept's viability, most have been enthusiastic about pursuing the concept far enough to find out if it will work, or not, for certain. This proposal includes work that should go a long way to dispel doubts about penetration, and signal-noise ratios obtainable.

Project Team:

Tom Billings - space educator and researcher

Allen Taylor - Principal Investigator on our project extracting geological features from spacecraft lunar image data. Assoc. Professor at Pacific University, Forest Grove, OR.

Ed Godshalk - a senior engineer at Maxim Integrated Products in charge of microwave IC package models. He has designed built and delivered 35 Ghz microwave integrated circuit voltage controlled oscillators for the SADARM Project which withstood 20,000 gravities acceleration.

Bryce Walden - Chair of the Lunar Base Research Team of Oregon L5 Society.

Cheryl York - Pres. & Treasurer Oregon L5 Society.

$124,129 Total Budget. Total Time 12 months

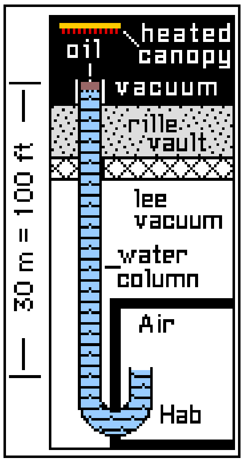
MMM

MMM #132 - February 2000

Liquid Airlocks

for Cargo in & out of Lavatube Habitats

By Peter Kokh



The weight of column of water 30 meters or 100 feet high exerts enough counter-pressure to keep habitat atmosphere at 0.5 Earth normal (42% O2, 58% N2) pressure from flowing out the open ended J-shaped tube.

A layer of oil, lighter than the water, keeps the water from boiling away into the vacuum while a heated hood keeps the surface warm enough so that neither oil nor water will

In MMM # 17, July 1988, we introduced the concept of liquid airlocks, not for people but for small and export items. The aim is to cut air losses through repeated cycling of conventional airlocks.

- Every effort should be made to preserve the high external vacuum of the Moon – priceless both for science and industry
- Even though oxygen can easily be replaced, nitrogen is rare on the Moon

The idea is not hard to explain to anyone who is familiar with a barometer, a common device used to measure fluctuations in air pressure as a clue to coming weather changes. A barometer is a bent glass tube, closed at one end, open to the atmosphere at the other end filled with a set amount of a liquid, commonly mercury. Sea level air pressure supports a column of mercury 76 cm or 29.92 inches high.

If you were to make such a device large enough in cross-section, you could run a conveyor belt through it to carry properly sized items out of the pressurized habitat into the surface vacuum, or vice versa. For some situations, this might be ideal

Mercury is very dense, 13.5 times as heavy as water. This keeps the size of the device compact. For a liquid airlock on the Moon, we would need to import considerable amounts of this liquid metal at great expense. If we use water instead, relatively much easier to source locally, the column needed to keep vacuum out of a sea-level pressurized habitat in one sixth gravity would be significantly higher: over 61 meters or 200 ft. But it is more likely, to minimize both the amount of nitrogen needed and stress on the hull(s), that we would use half that pressure level. That’s still 30 meters, 100 ft of water. This height is impractical for conventional subsurface facilities. It seems just right, however, for use with lavatube facilities and rille vault shielded outposts.

Water has a relatively low boiling point and a high vapor pressure, but both seem tractable. At the surface, a heated hood would greatly reduce the propensity of water to loose temperature to the cold of space, as well as shading the exposed liquids from the heat of the dayspan sun. A layer of oil would minimize sublimation into the vacuum. Goods in transit must be able to tolerate and shed this oil.

Of course, the conveyor belt must not snag, not ever! So the real “invention” here is not the barometric airlock itself to keep habitat air pressure safely inside, but the features that make it work as an avenue for bringing goods from the vacuum above into the atmosphere below and vice versa: the snag-free conveyor system that works well in four media: vacuum, oil, water, and air, and which has to be able to convey a variety of items in some useful range of sizes if it is going to be useful. This “invention” waits to be developed.

Other Liquids? – Gallium & NaK

Could other liquids be used? Gallium, 6 times as dense as water, would allow a much shorter column of liquid to do the trick and make liquid airlocks practical to use in conventional surface habitats that are shielded with just 2-4 meters of regolith. It is and liquid from 30 to 1983 °C (86 to 3600 °F) and that is very attractive. But on the Moon Gallium is a trace element not economically feasible to produce, so the amount needed (plus loss-make-up-surplus) would have to be imported.

NaK (pronounced knack) is a eutectic alloy of sodium (Na) and potassium (K) at 23% and 77% respectively. It is liquid just a little bit above room temperature up to about 800° C, a very serviceable range, and it has a high thermal capacity. Both sodium and potassium are sufficiently abundant on the Moon. in parts per thousand, to make local production eventually feasible. Discounting polar ice reserves, NaK is potentially the most abundant liquid producible from lunar regolith. But it has a density comparable to that of water so there is no advantage if shortening that 30 meter column is the goal. More importantly, it is nasty corrosive stuff.

Conclusions & Spin-up Research Opportunities

Twelve years ago, when we first broached this novel idea, it seemed impractical. The density of the working liquid right to fit the needs of surface-shielded habitats was offered only by Gallium. Polar ice seemed unlikely, and NaK did not behave well.

But for the elevation difference between the lunar surface and a lavatube or rille-bottom outpost, polar ice water now seems ideal. Are their spin-up applications on Earth that could drive profitable predevelopment of this technology? Perhaps as a clean conveyor system between the outside atmosphere and closed rooms with special, even toxic atmospheres for special industrial use? **MMM**

MMM #136 - June 2000

Nightspan Lighting

Sulfur Lamps & Light Pipes

By Peter Kokh

Getting through the 14.75 day long lunar nightspans successfully means having enough power to maintain both comfortable living conditions and productive activities. A successful “overnighting” program thus entails these elements:

- Available nightspan power either from a power source that is not sunlight-dependent or one that involves a suite of ways to squirrel away overabundant dayspan sunshine for nightspan use.
- Finding a way to separate out as much of the energy-intensive workload chores to undertake during the dayspan and as much of the energy-light, labor-intensive workload chores to get out of the way during the nightspan. This allows us to get through the nightspan productively with much less power than we use in dayspan.
- Designing power-needing systems to be as energy-efficient as possible, thus lowering the threshold for success even further.

One of these “power-needing systems” is nightspan lighting. Using fluorescent bulbs instead of incandescent ones is the sort of thing we have in mind. But now, suddenly, in the past two years, a wholly new lighting technology has begun to come online that can cut the power demand for lighting to only a sixth as much as even fluorescents demand! It is an astonishing development, all by one Maryland company, and one that is ideally suited to a lunar application. Sulfur Lamps working in concert with Light Pipes. It is something to get excited about.

Sulfur Lamps - http://www.sulfurlamp.com/

- Full Spectrum, like the sun
- Very Stable, both in color and brightness
- Very low UV and minimal IR / heat in beam
- Very Efficient, most efficient source available
- Long-lived, with minimal service requirements
- Environmentally safe, just sulfur and argon
- Quick to start, 100% in 25 seconds
- Operable in any position
- Dimmable to 20%, and maintains color
- Very consistent in performance, from unit to unit

The light source is an electrode-less sulfur lamp, invented in 1990 by scientists working for Fusion Systems Corporation in Rockville, Maryland. This technology is now being developed exclusively by a new company, Fusion Lighting, also of Rockville. In the next two years, the lamp is expected to find its way into a wide variety of applications: large interior spaces (factories, warehouses, arenas, shopping malls) as well as for architectural and security lighting. Two lamps and a single light pipe at the Forrestal Building are replacing almost 300 conventional lamps, ballasts, and fixtures.

At the National Air & Space Museum, overall light level has been increased fivefold, unwanted ultraviolet cut to almost zero, shadowing reduced, and color improved -- all with a 5/6 ths reduction in energy consumption. Given their small size, sulfur lamps are ideal for use as "light engines" for special fiber-optic uses as well as general lighting.

The negatives appear to be low. The system uses sulfur rather than the mercury used in all other high-wattage lighting systems. The disposal of the bulbs will be no problem for the environment. The bulbs may never need to be changed. Because there is no filament or electrode, there is nothing to burn out or break. The magnetron used to power the lamp will need to be replaced after fifteen to twenty thousand hours of use. The lamp is designed to make this changing easy. But the expectation is that these will be superseded by solid state devices to give the lamps an almost indefinite useable life.

What about lunar agriculture applications? The lamp has been well received by Agriculture Dept. scientists looking for ways to use this energy-efficient source to grow plants in the laboratory. One big advantage here is that the sulfur lamp has bright, full-color characteristics just like the sun. Fluorescents and other high-intensity discharge lamps, emit only bits and pieces of the full color spectrum. In a graph of light output versus wavelength (color), the output from the sulfur lamp coincides closely to sunlight over most of the visible spectrum.

Truer sunlight quality may also be invaluable for frontier psychological health. Indeed, there has been high interest in sulfur lamps from Scandinavia where the winters are long and dark.

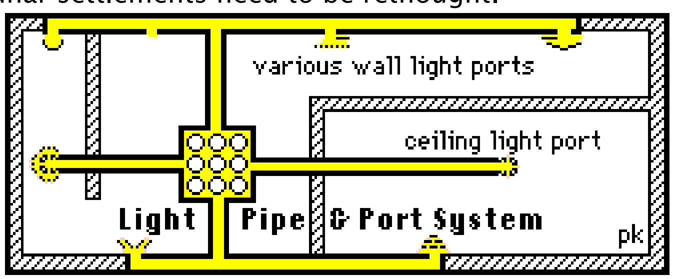
How do they work? Argon gas in the bulb is ionized by the microwave field and absorbs energy which is then transferred by collision to the sulfur molecules which, in turn, are heated, excited and emit light. Krypton would also work. The lamp is rotated to cool the bulb and also to mechanically stir or mix the plasma. The bulb weighs so little that only a very small motor with negligible power draw is required to spin the lamp. The argon and sulfur do not dissipate with time. Nor does the light deteriorate as with fluorescents or HIDs. The most popular fluorescence put out about 81 lumens per watt. The current sulfur lamp is at 95 LPW at the wall plug with new ones over 125 LPW available soon.

You can't go out and buy a sulfur lamp just now. The LightDrive 1000 and the Solar 1000 models used in tests to date have ceased production. The next model is still in R&D with no scheduled release date. According to Fusion Lighting, the future will bring even better all around performance.

Light Pipes

Light pipes are a delivery system not unlike "drip irrigation." Their whole function is to deliver light wherever needed, in the amount needed. Use of light pipes greatly reduces bulb replacement labor.

The 3M Corporation has taken the lead in developing and commercializing light pipe systems. We had reported on the usefulness of the new technology on the M (354 hours of guaranteed cloud-free dayspan sunshine) in MMM # 66 p.7 June 1993, "Let There Be Light: light delivery systems for lunar settlements need to be rethought."



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; 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.

The exciting good news is that now, all of a sudden, we have a much better option than the "high-powered sodium lamps" suggested above. The sulfur lamp bulbs deliver much more light from a much more compact golf-ball sized source. The smaller the bulb, the easier it is to mate with light pipe distribution systems. Light pipes driven by sulfur lamps are suitable for low and high bay uses requiring high quality, low shadow light such as factory floors, sorting facilities, inspection bays, and limited access areas. The new sulfur lamps have been used with light pipe installations in post offices, train stations, clean rooms, large freezers, auto manufacturing plants, aircraft hangers, and highway signage. Advantages of light pipes are low maintenance cost and the nonintrusive nature of lamp maintenance. This is still a new technology and improvements in performance and lower price can be expected.

Other Useful Light Delivery Systems

Another way to deliver intense light evenly over a large area is to use a central kiosk under an arched ceiling or to a special overhead diffusive reflector which provides uniform illumination to the floor area. Other installations in Sweden use wall mounted lamps that direct light to specially placed specular reflectors for general and special lighting needs. Directing light toward a reflector is best for low maintenance, limited access installations that need good efficiency.

For us, the Bottom Line

Both sulfur and argon will be reasonably easy to process from lunar regolith, and that will make lunar self-manufacture possible when settlement growth makes it economic to do so in comparison to continuing importation.

The new sulfur bulbs have only very long lasting components and are so efficient that lunar nightspan sulfur lamp lighting systems will only need a fraction of the energy we had previously expected to have to devote to this purpose. As nightspan power generation is very much an "uphill" effort, the fortuitous development of these two well-matched systems is thus very encouraging. Men have never "overnighted" on the Moon. Now we have less reason to "fear the dark." **MMM**

The World's Largest Sulfur Lamp

www.af.mil/news/Sep1998/n19980921_981433.html

Hill Air Force Base, Utah (AFNS) 21 Sep 1998: After years of planning, a demonstration of the world's largest sulfur lamp installation opened here. It features 288 energy efficient lamps with a 10 year life expectancy, covering a work area in a hangar the size of two football fields. The base expects to realize a savings of $57,000. The project's biggest benefit is expected to be a better quality of life for the employees who work in the hangar under the softer, more sun-like light.

MMM #138 - September 2000

Ramping Up R&D on Lunar Resources via the University of Luna - Earthside

If you can make it here, you can make it anywhere!

By Peter Kokh

Those who look at the Moon and see its many challenges as unmeetable might also find themselves coming up short in other more friendly places like Mars which does have many more resources than the Moon. Compared to the United States, Japan is very resource poor. But it has used the resource it has, the brains of its people, to do quite well all the same, thank you. The Moon does have the resources we need to get started, and advance to the point where it can trade for the other things it needs.

Getting started with what the Moon does have is the question. Those who plan permanent return to Moon but who are cavalier about these challenges, do us, and the lunar frontier,a considerable disservice. We must stop glossing over the challenges.

Some of us have brainstormed a few of these critical issues. But as educated laymen, we can only suggest paths that might be tried. We need to recruit those who might be able to walk down those paths.

We need to involve a rare breed of expertise -- people who are both knowledgeable in their fields, yet who are not captive to the assumptions prevalent among their colleagues and peers, but who are ready to find new ways, chart new territory. We must look for those mining engineers and chemical engineers who are one in a thousand, if not rarer.

It is time to take responsibility for making this happen. How? By putting into place the mechanisms and infrastructure that will foster and nurture this kind of radical revolutionary technological activity. Even if we are not able or qualified to do the investigations ourselves, we do have it within our power to create the environment and favorable conditions that will strongly encourage progress

Should we wait for nanotechnology?

In the past 15 years or so, since the heyday of first post-Apollo research using the returned soil and rock samples, almost nothing has been done of a non-theoretical nature. Is it premature? Should we wait until the nanotechnology messiah has reached its 30th year and is ready to go public with the gospel. I confess to being a doubting Thomas.

Even if nanotech can economically produce (isolate) pure elements from the homogenized lunar stockpile, that will not solve the question of doable alloys, glass and ceramic formulations, etc. for which we will have to get by without traditionally preferred alloy and other immixing ingredients. Nor will the nanotech savior solve any of the other hurdles that face us on the Moon. In time, nanotech may become a very useful tool, but not a panacaea. It is time to take the plunge now.

The University of Luna -- now!

In MMM #112, FEB '98, [above, pp. 61-66 I] as a prelude to a workshop on the subject at the upcoming ISDC '98, we printed a three page article on "Project 'U-LuCy', Founding the University of Luna in Cyberspace." The idea is not a bricks and mortar institution, nor of a teaching institution, but of a forum for keeping tabs on research done, research underway, and research still waiting to be tackled. While eventually U-Luna would have departments covering every field applicable to settlement, geology and mineral resources, and how to mine and process them and use them to serve domestic needs as well as provide exports - these of utmost import. We need mining engineers, chemists and chemical engineers, metallurgists. We need architects who can design modular "languages" that work with the qualities of the materials we can produce. We need rocket scientists who can develop engines to use lunar producible fuels. And more.

U-Luna could promote badly needed research by listing appropriate theses projects for students at other institutions. U-Luna could host periodic think tank conferences on critical issues. Job One would be to get the ball rolling, and keep it rolling. Today we are at a rusty standstill. Let no one doubt that.

WHO can/should/must do what?

The young Moon Society does not yet have a leadership core large enough to give this matter the attention it deserves. How then, do we begin? Rather than postpone this initiative indefinitely, we must go out and recruit the leadership that we need to begin.

This is a matter that the pro-Moon community has dismissed, to its collective discredit, too long. To the outside world, we look like a bunch of idealistic kids wet behind the ears. We do not give challenges and obstacles, obvious to others, due respect.

This is a Project, that once underway, can proceed either under the aegis of the Moon Society, or independently, co-sponsored by the Moon Society and the National Space Society. As many of the technologies and processes that need to be developed to open the Moon will be invaluable to the new Martians in making use of the assets of Phobos and Deimos, the Mars Society would do well to cosponsor this Project.

However we begin, begin we must! To kickoff, we propose a U-Luna-discuss list hosted by the Moon Society, in which those interested in this project can further brainstorm how to get it off the ground. We will post instructions on how to get aboard in MMM.

We have no chancellor. We have no Board. We have no faculty. Yet we must start! - PK

MMM #142 - February 2001

"Deadman's" Spacesuit Thruster Pack with Fail-Safe "Homing" Capabilities EVA Assured Safety without Tethers

By Peter Kokh

Astronauts in space suits gliding off into oblivion and certain death is a standby of science fiction film melodramas. The tether breaks - or is "cut" - or a hero-martyr disconnects the tether to retrieve something just out of reach. The umbilical tether has been part of Extra-Vehicular Activity [EVA] ever since Alexei Leonov took the first plunge out the airlock in March of 1965 (Voshkod 2), beating Edward White's solo (Gemini 4) by six weeks.

While eventually, NASA would test the MMU "floating free" Manned Maneuvering Unit backpack in nine untethered EVAs in 1984 (seven of them from the ill-fated Challenger orbiter), the umbilical safety of the tether has been a hard cord to cut. With the MMU, there was always the danger of an accidental overthrust, putting the wearer on a trajectory from which there was no recovery or return.

That was seventeen years ago, already! Computers have come a long way since then. There would seem to be no reason why smart "override" controls could not be built in, keeping tabs of changes in momentum and vector and distance as well as remaining thruster fuel, the suit would automatically override manual controls whenever the delta V needed to return to the airlock approached the limits of remaining fuel. The suit could also have a "deadman's" control feature that activated automatic return if sensors detected any decrease in suit pressure or prolonged inactivity. Homing beacons on in range airlocks would be part of the system.

Such a "smart" MMU would enable safe and worry free EVA by more than one person without the risk of mutual entanglement. The annoying problem of entangled cords is precisely what has made "cordless" power tools so popular in the work place!

While useful for construction and inspections and other work duties, our point is that such a suit would allow "frolicking" in space for the very first time! Frolicking, and unleashed sports. Perhaps even "Extreme" Space Sports.

At first, there might be only one model, especially for construction, repair, and industrial purposes. But once there are enough people working and living in space to increase the demand for a variety of challenging sport activities, manufacturers could start producing "sport MMUs" with special "handling" and "maneuvering" capabilities. Range, in terms of Delta-V units, along with acceleration, will be as important to space athletes as megahertz and gigabytes are to computer buyers.

But as long as "all there is to do" is to go for an aimless joyride through landmark-free empty space, "free-thrusting" will be little more than a short-lived fad. Development of a real and growing market will go hand in hand with the parallel development of EVA team sports and games, even "track & field" type individual events which one goes for a new "record."

The start could be something simple like a rally around an ISS management sanctioned course around the periphery of the station with its many modules, struts, solar panels -- in and out of plane. To minimize accidents, the smart suit would have to have proximity sensors that would override manual controls in time to take evasive action. The idea. of course, would be to get as close as one could to a rally point without triggering the override as that might re-vector you out of the competition in a direction not of your choosing! If a game, sport, or event does not challenge one's skills, what good is it?

An alternative would be a co-orbiting rally "course" with a set of station-keeping market buoys. Their mutual positions could even be randomized from one event to another, the proper sequence indicated by beacon color perhaps. Space suit "team sports" could come in time. Touch Spaceball? Make the suits light enough, agile enough, and smart enough, and all fetters to the imagination will face away. How far away is such a day? Perhaps a generation, to be conservative, not much more. Certainly, a risk-averse NASA will never allow such frivolities. We will see the rise of such activities with the appearance of orbital tourist resorts.

There is more to space than rockets and modules. The space suit has equal power to make or break the future. Present NASA suits are cumbersome and motion-restrictive and require hours pre-breathing and special atmospheres. Efforts to develop better suits -- and thruster packs -- have fallen victim to low-priorities and mis-budgeting. It will be up to the space tourist economy to give birth to less restrictive and more comfortable and more agile suits. **MMM**

MMM #151 - December 2001

Engaging the Surface with Moonsuits instead of Spacesuits

"Mother Nature has a Dress Code!"

By Peter Kokh

In last month's issue (MMM #150 NOV '01) we began our discussion of learning how to be "at home" on the Moon with articles on domesticating regolith, getting comfortable with overnighting, and learning to live with the Moon's natural rhythms. But there is much more to this agenda, and we pick up the litany this month. First on the list: lunar space suits!

Space Suits have traditionally been designed to protect us from alien environments, not to engage those environments on a "let's make ourselves at home" basis. These would seem to be just empty and cheap words at first reaction, but let's play with the idea, follow it, and see if it leads somewhere new.

When NASA sent astronauts to the Moon, it was with suits designed to protect them from a poorly understood and understandably "alien" environment. They did have a good understanding of the thermal loads and heat-management problem, of the radiation flux at the Moon's surface, and some inkling of the uncooperative character of the pervasive moondust. In designing the suits, it was essential to err on the side of overprotection. After all, the scientific goals of these missions were definitely secondary to the overriding directive to "bring 'em back alive!"

When we return to the Moon, the controlling directive will be to learn how to stay. Breaking the systems engineering and psychological barriers of overnighting will be at the top of the list of milestones in this campaign. And that will mean that we must have suits that can do more than handle the moderate "midmorning" solar heating loads. They must be up to handling the higher heat loads of "high noon" and of the lunar "afternoon" period (remember that from sun up to sun down takes a full 14 and three quarter standard Earth days).

But in order to do outside routine and emergency housekeeping, maintenance, and other chores during the equally long sub-bitter cold nightspans, the suits must have a controllable heating capacity with high reliability. Proper insulation against heat loss by radiation to the black sky will be essential. So even without the extra features we will identify as desirable below, the suits for the return missions will have to be improved, at least in thermal management capacity, over those of the Apollo era. So much for the obvious.

What we want to talk about in this article is the need for Moon Suits that go beyond such improved basics. We need to put to work the tremendous electronic telesensing abilities that have become doable in the three decades since the Apollo feats.

Smart Suits

For safety' sake and to maximize the odds of safe return, or rescue if that should ever be necessary, we can build a number of sensors and computer processor chips into our new "smart" moonsuits. The wearer should have at his or her demand, all of the following kinds of vital information:

- power reserves and time available at current energy consumption rates
- oxygen reserves and time remaining at current consumption rates
- thermal management stress loads as a function of capacity
- radiation flux with screen becoming activated when flux exceeds normal range
- built-in GPS (global positioning system) distance covered (GPS track) over the horizon landmark locator (GPS calculator) direct return route distance (GPS calculator)
- warning when the capacity of any system approaches the "point of no return" level

The readouts from these devices could be either constantly visible, or projected on the visor "heads up" area either when activated by a voice command or automatically when a caution or emergency condition develops. No one needs to be unnecessarily distracted by boring confirmations that everything is "functioning within normal parameters," but information that requires attention, must have a way to get attention. An alternative to a heads up display for less critical information would be a sleeve readout device.

A transponder belongs in every moonsuit. It could broadcast its signals via satellite or via a relay at one of the Lagrange point station (L1, L2, L4, L5 -- according to one's location on the Moon's surface). To personnel at the outpost or vehicle from which the suited excursion originated, the wearer's position would be monitored (as a backup system in addition to the suit's own GPS monitor.) If there was sign of inactivity lasting long enough to cause concern, or a cut off in transmission, or a signal that a suit function had failed or been compromised (e.g. even slow depressurization from suit puncture), the wearer's location would be pinpointed. Additionally, if someone sensed s/he was in trouble, the whereabouts of any nearby persons also out on the surface could be ascertained, and a route to their location plotted or a signal sent.

One of the tradeoffs of such safety features is that if the Big Brother aspect. There are times when one may want to be alone -- just him/herself, the moonscapes, and his/her thoughts. One should be able to turnoff a transponder, but with a double switch to prevent accidental disconnects. These kinds of :"Guardian Angel" features are well within current technology limits. They would make us more safely "at home" on the Moon. There is more we can do, so stay tuned.

Smart Visors

Not only can we thus greatly improve moonsuit safety features as described above, we also have it within our power to greatly enhance the wearer's perception of his/her environment. In comparison to the "Native Scout" expert clue recognition abilities that moonsuit wearers will "put on" when they don their suits, the Apollo moonwalkers had all the clueless sensory capacity of city slicker dudes. No offense intended, of course! They were all genuine heroes of the first rank who did all they could and more with the tools we gave them.

Our point is that it is not enough just to be able to look through a helmet visor with the naked eye. Moonscape's are notoriously monochromatic and the immense information that they bear comes across to the naked eye as a monotonous blur of seemingly trivial details. Smart Visors and other
electronic sensory enhancers could change all that, and allow the wearer to see an immense

variety of significant information of scientific, prospecting, or other value that normally fades into the monochrome overload.

Smart Visors and other sensory enhancers will allow future moonwalkers to “engage” the Moon as never before, by letting them see and sense information clues that “naked eyesight” just can’t detect, notice, or pick out. Here are just some of the possibilities that are within our means.

- Infrared scanning of the ink black shadows and knee-mount shadow penetrating spotlights
- Phosphorescence sensors
- Picking other humans out of the background
- Exaggeration of slight and subtle color difference
- Telescopic zoom-in capacity
- Sensors that sniff any outgassing in the area
- Range finder (distance to near horizon features can be greatly misjudged by the naked eye according to Apollo EVA experience)
- Level horizon guide (in low gravity, one’s ability to detect slight slopes is impaired)
- Filters that enhance visibility through any dust electrostatically suspended over the surface
- Alert-alarm and activation of laser spotlights when sensors in combination with expert recognition systems detect the special spectral and reflectivity signatures of minerals etc. on a field science or prospecting watch list
- Alert alarms for any motion in the visual field
- Alert alarms for any motion in the shadows
- Other expert recognition programs
- Major computing power to analyze inputs (the computer design should address the clumsy gloved fingers vs. keypad issue using voice recognition software and other means, be able to calculate mineral and element abundances of samples, and, using GPS and range-finding data draw simple but functional “map” guides)

We’ve probably missed a lot of other possibilities and if readers have some suggestions to add to this list they are encouraged to contact us email: KokhMMM@aol.com

But the list above will give some indication of the enormous potential there is to use today’s electronic wizardry to let future moonwalkers be vastly more attune with and aware of their environment. “Engaging the Moon on its own terms” is what we are after -- the ability to be able to see critical information normally lost in the visual monotony as if one were an experienced native-born scout.

Wearability and Mobility Issues

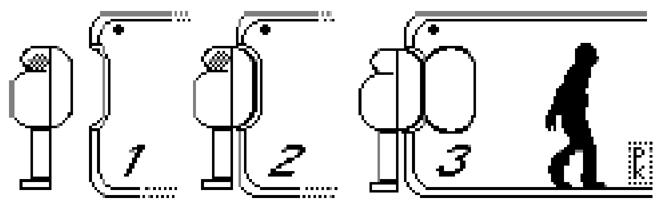
Comfort and Convenience were justifiably secondary concerns fro the designers and fabricators of the Apollo moonsuits. One can put up with most anything on a temporary basis, so long as the discomfort or inconvenience is not great enough to compromise the work at hand. But now we are going back to the Moon, intending to stay, intending to make ourselves at home. Field scientists (geologists, mineralogists, etc.) and prospectors and others will be out on the surface for longer periods, and repeatedly. In such circumstances, discomfort and inconvenience risks compromising the work at hand.

What do we need here? Surely, suits that are easy to put on and easy to take off without assistance; and suits that do not require pre-breathing special air mixtures. We need to make it so wearing proper apparel to go outside on the Moon is no more of a big deal than wearing proper apparel for rain, cold, wind, or snow is for us on Earth. In short we need suits that protect us without a lot of bother and drama.

We shouldn’t attempt to find an ideal design that offers such features in isolation from the even more important issue of dust control. The use of conventional airlocks will inexorably lead to the in-migration of annoying and trouble making amounts of fine powdery moondust into pressurized habitats, labs, workspaces, and other facilities. Previously we have proposed a solution prefigured in illustrations by the great lunar outpost illustrator, Pat Rawlings -- the clamshell-back or turtle-back spacesuit. We described its operation in the MMM #89 article cited at the bottom of this article.

Pat Rawlings who did the illustrations Ben Bova's 1989 book "Welcome to Moonbase" [Ballantine Books, New York, ISBN 0-345-32859-0] has elsewhere illustrated a much superior dust-control approach. The cover of "Lunar Bases and Space Activities of the 21st Century" [W.W. Mendell, Editor; Lunar and Planetary Institute, Houston 1985, ISBN 0-942862-02-3] shows personnel wearing what I have come to call the "Turtleback" suit, in which an oval hardshell backpack covers the torso and back of helmet. This backpack is hinged on one side, and entry to the suit is made through the opening.

"In prerelease conceptual illustrations Rawlings did for the David Lee Zlatoff/Disney/ABC '91 movie "Plymouth" (still the only science fiction film ever made about settlement and the idea of using lunar resources), there are sketches of turtleback conformal airlocks (my word) into which this specially designed backpack makes a sealed connection, then swings open, allowing the incoming astronaut to (pulling his hands and arms out of the suit sleeves) reach back and up through the opening to grab a bar above the inner door of the lock and pull himself out of the suit and into the habitat. The suit and most of its dust remains outside, perhaps to be stored automatically on an adjacent rack. Whether Rawlings himself ever thought through his artistic concept this far, or further, is unknown to this writer. But we want to give him full credit."



Next we need suits which are as light as they can be made, and agile! There are probably things we can do with both the boots and the loves to make the wearer more sure-footed in all types of lunar terrain, and more dexterous in handling samples, climbing, making repairs or performing service operations. If our moonsuits constrict our mobility and agility, making us "all feet and all thumbs," wearing them will exhaust us all too quickly, decreasing both the amount and the quality of work accomplished.

The amount of quality work that gets done per person hour is the name of the game. In time, it will also be a question of enabling people to go out on the surface to engage in field hobbies and out-vac individual or team sports. If we meet the needs of the scientists and prospectors, we will enable those with an "outdoors" recreational needs as well.

Out-vac exercise and sports activity of any kind will depend on the invention and debugging of a lightweight, supple pressure suit that can handle the heat and perspiration loads generated. If total out-vac exposure times are kept to an acceptable accumulative minimum, radiation protection can be minimized. Given the considerable benefit and boost to overall settler morale, the development of such a suit is sure to be on the collective front burner. Such suits will have to have many "smart" features we have described above.

For both work and recreation, overall morale enhancement is the real prize. Upon this morale hangs the long term viability of lunar settlement. Now unlike providing sensory enhancement, providing EZ-wear suits that allow maximum mobility, agility, and dexterity is a goal much more easily described than realized.

Our intent is not to give clues as how we can meet these goals, but to define what these goals should be. NASA has long been aware of the shortcomings of its spacesuits and for a time was funding two different teams to come up with replacement designs. Then the work stopped. There may have been some Agency dissatisfaction with the results being achieved in the two projects underway. Each was promising advantages, but by means that were mutually incompatible so that all the proposed advantages could apparently not be realized in either design. But we think that the real reason for shelving these two projects was Neanderthal budget-cutting, by those who could not see the big picture, or cared.

This kind of R&D needs to be directed by a commercial enterprise that has a stake in the results and in the quality and quantity of work done on the Moon. For now, brainstorming and paper studies of radical new moonsuit designs that meet these objectives are about all we can hope to see -- until some intently for-profit consortium has a eureka-dream that "there's (a) gold(mine) in those (gray) hills!"

Active Helper Systems

One could also imagineer a number of "helper systems" that would enhance the surface excursion experience even further. Power tool plug-ins Set II. In addition to tools useful in investigating rocks and minerals (drills, saws, core samplers, etc.) and various glove and boot accessories, we could "plug in" more exotic, even "handier" tools. How about an automatic laser device that would leave "Reeses Pieces" "hot spots" that would remain detectable for a few hours to assist the wearer in retracing steps especially in jumbled and confusing terrain?

Or how about a retrievable tethered mini "scamperer" probe that could reach spots (up/down cliffs and escarpments, inside crevices and clefts, etc. and other hard or inconvenient to reach areas) and either analyze what it detected and send back the data or pick up and return promising samples? The second season team at the Mars Society simulation outpost on Devon island discovered the surprising usefulness of such critters. They experimented with 100 m and 200 m tethers (leashes, anyone?)

We'd be delighted to hear from readers about more such active helper systems. Think of them as productivity maximizers and safety insurers.

The Fremen Stillsuits of Dune/Arrakis

Okay, so that's a bad title in as much as those who do not allow the pleasures and escapes of science fiction into their lives will have no clue of what it means. To Sci-Fi fans, no explanation is needed. So let's try again.

Accommodating Human "Needs"

Our suits of the Apollo moonwalkers had provision for urination -- a definite improvement over the one Alan Shepherd wore less than a decade earlier. But these suits were made to enable stays of a few hours at most. We'll want to do some trial and error experimentation with alternatives that will cover our butts, so to speak, for longer periods under both normal and distressed conditions (er when it's Immodium time). Accommodating for regular bowel function (other than by the "low residue diets" fed to the Apollo crews) within the tight confines of a space suit will pose quite a challenge, but one we must meet sooner or later, so why not sooner?

Truly long-duration suits would have the capacity to was the gist of the first subtitle for this section. Now that will make many queasy but it is no more than a very accelerated version of what happens in nature. So if this makes you ill at ease, get with the program!

Suits will have controls to adjust the gas composition of the air, and scrubbers to remove or recycle exhaled carbon dioxide. To create a "micro" biosphere system to handle all this indefinitely without frequent fresh inputs would seem an impossible challenge. Fortunately, some people relish "impossible" challenges. We predict breakthroughs in this area -- in time, and not by an "agency."

The ultimate backup system would be a noninvasive vital signs telemetry system. That is a nearer term goal, one we should find easier to meet. Wrap Up - "Moonskin"

Actually, we are all born with a space suit of sorts -- our skin, which is one of the most important yet least appreciated of the body's essential systems. The skin works to keep our body fluids in and contaminants out. But this natural integument evolved to meet the challenges of our terrestrial environment. Now as we move out into spaces and places beyond our native atmosphere, we do not have the time to let "evolution" do its work in spinning us an improved formfitting protection layer.

But the way the skin works without encumbering us to assist our mobility, agility and dexterity is the model we must hold before us in designing our "moonskins" the suits that will let us be at home on the Moon as if we were natives. With the right outerwear, we could operate freely on the Moon's surface and be attentive of all the clues the moonscapes hold. Well-designed moonsuits well let us "belong" in our adopted homeworld.

Relevant articles from MMM issues past: #89 OCT '95, p.5 "**Dust Control**" § "**Engineering Countermeasures - Suit-Locks**" #96 JUN '96 p. 6 "**Spacesuit Aversion**" **MMM**

MMM #154- April 2002

N Nitrogen N_2

Symbol **N**
Atomic Number **7**
Atomic Weight **14**
Molecular Gas N_2
Molecular Weight **28**

Nitrogen and the Moon's Future: Conservative use of this scarce critical element is key to "limits to growth" of Lunar Settlements

By Peter Kokh

Cosmically speaking, Nitrogen is one of the universe's more abundant elements. Earth's atmos-phere is 79% oxygen. There is three times as much (by weight, not by percentage) on Venus. Mars' thin atmosphere is 3% nitrogen. Titan's thick atmosphere has more Nitrogen than that of Earth. There is plenty in the deep atmospheres of the gas giants.

All that does little good on the Moon. Unlike the Earth, the Moon formed "hot", condensing out of the hot plasma debris of a major crash between the proto-Earth and another early planet-in-formation. In the heat from the impact, almost all "volatile" elements, those with relatively low boiling points, were driven off into the surrounding space, never to be recovered. When the Moon coalesced from this debris, it formed "dry" - no water, no free gasses. Any carbonates were disassociated and the carbon driven off. Only oxygen, which forms tight stable bonds with most metals, was retained.

What nitrogen is found on the Moon is from two external sources, one known, the other surmised:

Known regolith reserves: nitrogen atoms in the thin but incessant solar wind have become affixed to the fine particles in the dusty topsoil blanket that covers the Moon: the regolith. This resource is primarily in the top meter or so at an average of 82 parts per million.

Possible polar ice reserves: if the suspected polar ices "found" by Lunar Prospector are confirmed by a "ground truth" probe, it is almost certain that they are derived from cold trapped vapors released when comet fragments have impacted the Moon. Comets consist not only of water ice, but of nitrogen oxide and carbon oxide ices as well, in a mixture dubbed "clathrate." One of the primary goals of a polar ground truth probe would be to qualify and quantify this mixed ice bonanza. Someday there may be refineries at the poles producing CH_4 methane and NH_3 ammonia as well as water, for shipment by truck, rail, or pipeline to industrializing settlements in other areas of the Moon.

Off-Moon sources: import of nitrogen in the form of ammonia, from comets and asteroids if and when such resources can be economically developed to provide steady "pipeline" supplies.

The Bottom Line:

On Earth, an 1800 sq ft home with 9 ft. ceilings, at sea level, contains a half ton of nitrogen. To provide that much on the Moon would require gas scavenging an average of 6,100 tons of regolith at 100% efficiency. Anything we can do to cut that burden will allow settlement to grow more quickly.

Of all the elements essential for life (oxygen, hydrogen, carbon, nitrogen) it is nitrogen that is in shortest supply on the Moon in comparison to the amounts of it we are accustomed to using -- simply as the buffer gas for our oxygen-based breathable air. As settlements grow, it will not be shortages of hydrogen (water) or carbon that put on the brakes. It will be nitrogen that becomes the pinch point.

The Case for Reduced Air Pressure

One way to "go easy on the nitrogen" would be to simply maintain and regulate low ceiling heights in lunar settlements, not just in private quarters, but also in public places. Less volume of air means less tonnage of nitrogen. Such a Spartan constraint would not exactly foster high morale, especially over the long haul. But without other ways to conserve, we may well be facing such a gloomy prospect .

What else can we do? Reduce the air pressure in habitat areas. Additional savings could come from reducing the relative abundance of nitrogen in the reduced atmosphere, keeping the partial pressure of oxygen closer to what we are accustomed.

Readers who frequent the Artemis Discuss List will no doubt be exasperated by this suggestion.

"Oh no! We've been through all this before! It can't be done, and NASA uses Earth normal pressures and mixtures in space. An Artemis-list discussion hashed this out in considerable detail. It is not true that we cannot live in lower air pressure. Air pressure at 7,500 feet is not significantly less that at sea level."

With all due respect to those who took part in this discussion, we believe all the premises behind these assertions are flawed and inaccurate. It is vital for those of us who have faith in a bright future for lunar settlement to seek out a second opinion.

The Facts:

A table on the reduction of air pressure with increasing altitude is available online at:

http://www.cleandryair.com/AltitudePressure.htm

Sea level air pressure is the equivalent of a column of Mercury 760 mm high (30 inches).

Here is what the table shows for some higher altitudes:

Altitude	Pressure	% (1 ATM = 100%)
7,000 ft.	586.7	77%
(Mexico City's 22 million live at 7,600 ft.)		
8,000 ft.	564.6	74%
(Bogota's 7 million live at 8,600 ft) (Nairobi's 2 million live at 8,800 ft)		
9,000 ft	543.3	71.5%
(Quito's 1.5 million live at 9,500 ft)		
10,000 ft	522.7	69%
(Cuzco's 300,000 live at 10,600 ft) (La Paz, Bolivia's 1.5 million live at 11,800 ft)		
Millions have been on top of Pike's Peak, 14,000 ft		
15,000 ft	429.0	56.6%

Can thirty five million people be wrong? It is quite clear from these figures and the interposed list of high altitude cities where millions live, that the Artemis-list conclusions are prima facie in error.

"Nevertheless, a very large portion of the population has difficulty adjusting. Also note the life spans of the places you've listed."

It was noted during the Mexico City Olympics (1968) that those athletes who live at lower altitudes had enormous difficulties competing, unless they had the foresight to come to Mexico City a week or two early to acclimatize themselves. Those who did so did well. And life spans relate to medical care.

The argument from the experience of some people who have difficulty adjusting is irrelevant. It cannot be expected that everyone would be able to adjust to life on the Moon or Mars, and there are a lot of reasons for that: claustrophobia, black sky blues, loss of open-air living, lower gravity, air pressure. We know all that, and have always known it. Pre-screened settlers will come from the ranks of those who tolerate all these conditions well.

All that is necessary for settlements to thrive is that there are enough who can adjust.

Those who argue from the admitted fact that some cannot adjust ignore the rules of simple logic. "Some people do not make good parents, therefore parenting is unwise." Same type of argument.

There are a great many skeptics about the rationality of our faith that humankind can sow itself on other shores beyond Earth's. "We were evolved at 1 ATM and 1 G and it is not possible for us to be pre-adjusted to tolerate anything less!" If we are to give in to them on the atmospheric pressure question, then we might as well give in to them on the gravity issue. But let's not. Life is about adaptation, not only over many, many generations, by evolution, but within the experience of individual lifetimes. Humans originating in East Africa have dared to step out of "their niche" over and over again to the point where we now thrive from the polar arctic to the high altiplano of Lake Titicaca and La Paz, Bolivia.

Why Air Pressure is a Critical Issue

The suggestion to use reduced air pressure in our outposts and settlements on the Moon and Mars is not lightly made. It is simple physics that the higher the inside/outside pressure difference, the greater the propensity to leak air, and the greater the likelihood of seal failure.

And this likelihood increases on a geometric scale. Choosing a reduced air pressure is then first of all a matter of common sense safety. The Moon and Mars are very unforgiving places. If we respect the dangers and the risks, our chances of successful transplantation to either world will be that much greater. Not to do so based on assumptions born out of history or habit or respect could invite failure. We have a saying that "it is easier to find forgiveness than to get permission." That approach works with people and institutions, but not with Nature.

Extra incentives for Lower Pressure on the Moon

On the Moon we have three additional incentives to use reduced air pressure in our habitats:

- The more our habitats leak, the more likely we will end up "polluting" the lunar vacuum to the point that it ceases to be a major industrial and scientific resource.
- The more our habitats leak, the more nitrogen we **will** lose (nitrogen is enormously more difficult to come by on the Moon than oxygen) and the sooner we'll reach the Moon's "carrying capacity"
- The less nitrogen we use as a buffer gas in our habitat atmospheres, the less expensive it will be to provide higher ceilings in public spaces as a welcome relief to eye strain and cabin fever.

Reducing Nitrogen Richness as well

One of the cases made against reduced air pressure is that "some" people have difficulty adjusting to it. Aside from the irrelevance of this argument, the difficulty cited comes entirely from the proportional reduction in the amount of oxygen. But who says we have to keep the same gas ratio we have on Earth (79& nitrogen, 21% oxygen)? What if we were to keep the oxygen partial pressure at comfortable levels and achieve all of the reduction in total pressure by reducing the amount of nitrogen gas used as a buffer? The following table assumes just that:

Mix (N/O) (N2/O2)	Pressure (%1ATM)	N2 Savings (tonnage)
75/25	84%	20%
70/30	70%	38%
65/35	60%	51%
60/40	52.5%	60%

But, but ... fire risk and oxygen poisoning

Most of us know the dire consequences to the Apollo 1 crew of using an atmosphere of 100% oxygen. One spark and they were toast. There is, however, an enormous difference between 0% nitrogen and say 60%. But let's humor those concerned about fire risk and admit, for the sake of discussion that a 60/40 nitrogen/oxygen ratio makes combustibles more likely to ignite.

On Earth we are surrounded by combustibles. For one thing we use a lot of wood, a lot of plastics. On the Moon, however, items made of wood and other organics, natural or synthetic, would be very very pricey. We will need to reserve all the nitrogen, hydrogen, and carbon we can harvest for biosphere biomass and food production cycles. On the Moon we will rely much more heavily on inorganic substitutes: metal alloys, ceramics and cast basalt, glass and glass composites. The typical lunar home, office, school, or other kind of space will have very little in the way of combustible materials outside of clothing, bed sheets, towels and the like. Even the casings for electrical wiring are more likely to be of woven fiberglass than Romex plastic. Electrical fires will be much less common than on Earth.

All this is good, because fire is far more likely to be fatal on the Moon than on Earth, You can't just open a window to let out the smoke. You can't just open a door and escape outside. Future Mars settlers will be under no such materials rationing restrictions. The sad twist is that the incidence of fire and fire fatalities on Mars is likely to be much greater.

Some fear oxygen poisoning in an oxygen enriched atmospheric mix. But this phenomenon only occurs when the oxygen mixture is near 100%.

Don't sea level crops need sea level nitrogen?

On the Moon we are surely going to want to grow more than coffee, tea and other crops usually associated with high altitude. The altiplano of Peru and Bolivia are not exactly gardens of Eden or bread-baskets to the world! Yes, but!

It is true that this high altitude area on Earth is no green paradise. Is that the result of reduced nitrogen? If that is the conclusion you want to reach, it will be the most plausible answer. But in fact, the altiplano is relatively infertile for climate reasons that have nothing to do with the reduction in nitrogen partial pressures. The are is colder because it is higher up. An because it is on the lee side of the Andes, it is drier, and windier.

Dry, cold, windy -- not exactly the conditions that make for rich, fertile soil. But to jump from that fact to the conclusion that reducing nitrogen partial pressures will mean cold, dry, windier lunar settlement interiors with poor soil is absurd.

In fact, in response to the quickly rising population of the area, especially around La Paz, there has been much agricultural research of late and the results are amazing.

- http://www.idrc.ca/books/reports/09highla.html
  - onions, radishes, beets, and carrots and lettuce at 4,200 meters (13,839 ft.)
  - potatoes: three harvests a year in greenhouses
- http://www.eco.utexas.edu/graduate/Blubaugh/papers/ISEEpaper.htm
  - sustainable development in Bolivia's Altiplano

If you do a web search for altiplano crops or altiplano farming, you will find much more evidence to support the conclusion that high altitude and lower nitrogen partial pressures do not mean having to live on coffee alone. But how can this be?

Simple. Most plants do not get their nitrogen directly from the air. They absorb nitrogen from the nitrates in the soil, put there by microorganisms that can fix nitrogen directly from the air. Some plants, like legumes (bean family) live in symbiotic association with such micro-organisms and planting them enriches the nitrate content of the soil. But the bottom line is that nitrogen-fixing micro-organisms thrive at all virtual altitudes under discussion. “Sea level plants” do not require “sea level nitrogen.”

NASA Studies

What about NASA studies? The assertion is that NASA has studied all of these questions exhaustively and come to the conclusion that sea level air pressure and mixture is best. Why else would both the former Mir and the International Space Station use 14.7 pounds of air pressure?

NASA has done many great things. But there are good reasons to believe that it is highly unlikely that research on this question has been exhaustive.

- NASA has never looked that far ahead to the point that human expansion might be limited by the availability of nitrogen. NASA’s lunar outpost studies have focused on small crew installations with individuals serving short terms of duty. For NASA to spend research dollars on “far future” options would be wasteful in that light.
- NASA has wisely chosen standard sea level air pressures and mixtures because man-hour time in space is prohibitively expensive, too much so to waste any of it on “adjustment time.” Once we start talking about settlements, where people have come to spend the rest of their lives, a short period of adjustment difficulty (for which all volunteers will already have been pretested before leaving Earth) is hardly a major concern.

But is it not brash and rash and disrespectful to NASA to request fresh research? In science, it is standard practice to check and recheck results of others. In medicine it is standard practice to request second opinions. If NASA is offended, then it has put itself on some sacrosanct pedestal above other scien-tists and researchers. No disrespect is intended.

There is simply too much at stake on this question to settle for results of past studies there is every reason to believe have not been exhaustive or free from preconceptions that tend to color results. Instead, let’s put all prior conclusions on hold, and mindful of the non-trivial consequences, examine the facts afresh with an open mind.

We owe our dreams that much. **<MMM>**

MMM #196 - June 2006

Scientific-Industrial Utilization of the “Lunar-Unique” Environment

By Peter Kokh

- **High vacuum** (vastly cleaner and higher than in LEO)
- **No global magnetic field** (unlike in LEO)
- **Fractional gravity** (mechanical advantage over LEO’s 0-g)
- **Minimum atmospheric activity** (levitated dust at dawn)
- **Seismically stable** geological structure
- **Sterile environment** (no air, water, soil pollution)
- **Slow rotation** once every 29.5 Earth days
- **Minimal seasonal thermal variation** (3° F/C?)
- **No humidity/water vapor**

The challenge is to identify scientific, chemical, and industrial processes that one or more of these unique environmental characteristics makes practical or possible on the Moon that are impractical if not impossible here on Earth or in Low Earth Orbit (i.e. at ISS or other future orbiting laboratories or factories).

Yes, you’ve heard a similar question posed before: what can we do in the micro-gravity of Earth orbit that we cannot do here on Earth’s surface? We have yet to find potentially profitable and practical applications for processing and manufacturing at “zero-g” (“micro-g” may be more picky-accurate) in space stations and orbiting factories. But that should not discourage us from looking for similar advantages that the Moon’s unique environment may offer.

That LEO offers zero-g and the Moon only 1/6th gravity is not grounds for dismissal. “Fractional gravity” may preclude some chemical processes but it confers a very real mechanical advantage to material handling and other mechanical operations. And the Moon offers advantages that LEO or other orbital locations do not:

The vacuum above the surface layer that is periodically “spoiled” by levitated electrostatic dust at dawn is much cleaner than the permanently dust and debris ridden low Earth orbit area, simply because that light one-sixth gravity continually purges that vacuum of foreign material including corrosive free oxygen.

LEO is very much affected by Earth’s global magnetic field. The Moon, lacking such a field, has the advantage whenever background magnetism can affect a chemical or physical reaction negatively.

The Moon supplies an extensive seismically quiet (in comparison to Earth) platform for use of **global telescope arrays.** The only disturbances come from impacts, not tectonic plates in movement. Are there other advantages to this seismic quiet that may benefit research or industry?

That the payoff is yet to come from the so-called advantages of “doing it in Earth orbit” should not dissuade us from looking for possible processes and research that are uniquely favored by the special combination of scientific environmental assets given above to “doing it on the Moon.”

If there are no areas of industrial and scientific activities better suited to the Moon than to either Earth or Mars, that would be surprising. The payoff to those advantages we find and are able to leverage could make minor contributions to the economic viability of lunar settlement. But until we find out otherwise, we cannot rule out the possibility that the payoff could be economically significant.

This line of research is certainly worth pursuing, and some of this research may not need to wait until we find ourselves on the Moon with adequate laboratories and other facilities. The issues are technical, however, and it is for specialists in each of the many areas of science and indus-try to identify operations that would benefit form the “Lunar-Unique” environment.

If lunar settlement and industrialization is to be viable, every area of possible advantage must be explored and pushed to the limit.

Some likely applications:

Biology

- Quarantine Lab for Mars Sample Returns, Europa Sample Returns

Astronomy

- Radio and Optical Telescope Arrays (interferometers)
- Northern and Southern hemisphere telescopes that can be set on a given stellar object 24/7/365 (vs. a fraction of each day for only a part of the year)
- Very large Arecibo-type radio dishes in craters, of which many thousands would be suitable

Energy

- Solar power arrays

Architecture/Construction

- Very tall towers are possible, kilometers high, for observation, relays, cable and cableway suspension, etc.
- Extensive use of Magnesium and ironfor surface construction it (both would quickly oxidize on Earth)

MMM

MMM #198 - September 2006

The Outpost Trap

THE OUTPOST TRAP

Technologies Needed to Break Free

By Peter Kokh

Despite the best of current announced intentions, it is politically and economically predictable that NASA's lunar outpost (even if is "internationalized" by taking on "partners" in a contract) will be stripped of any and all features seen as "frills" or "extras." Consider how the planned 7-man International Space Station was summarily slashed without partner consultation in the stroke of a presidential pen to a 3-person one: 2.5 persons needed for regular maintenance and a half-person is available for scientific research. It can and will happen again, unless ...

It becomes our cause, the accepted challenge of those of us who owe it to our own dreams, to do everything in our power to get the outpost built, outfitted, and supplied on a more rigorous and stasis-resistant path. The/a lunar outpost must be designed with expansion in mind, with a suite of easy expansion points, expressing an architectural language that is expansion-friendly. No all-in-one "tuna can stack," please!

To this end, we must reexamine every aspect and angle of setting up a lunar outpost.

I. Transportation System Architectures:

Designing cannibalizable items for strategic reuse in Earth-Moon Transportation Systems.

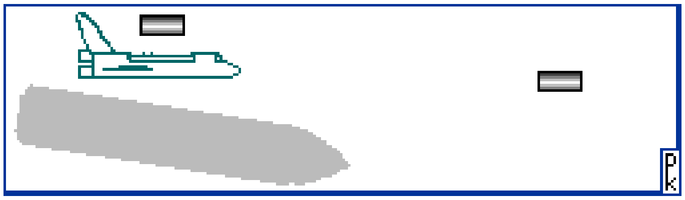
NOTE 1: The author is not a rocket scientist, engineer, or architect. The examples given below may not all be feasible, but we hope that those that are not, will suggest other possibilities that are worth exploring.

NOTE 2: We do not expect NASA to embrace any revolutionary space transportation system architectural turnabout. But it is something that commercial space transportation providers might do well to study.

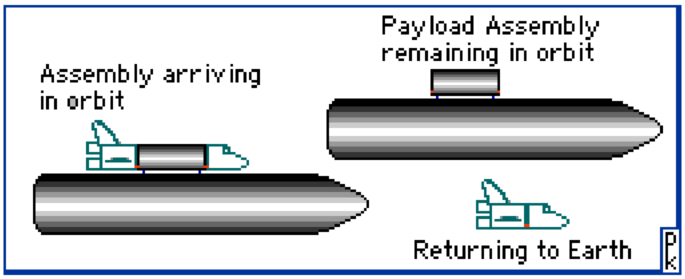
NOTE 3: Those in the business may be quick to insist that these ideas are all impractical. So be it. They are not part of the solution. We are looking not for those who say "it can't be done," but for those who say "we'll find a way to do it anyway!" If it were not for the "Young Turks" in various fields, we would all still be swinging from the trees. We must find the hidden, unsuspected pathways!

Way back in MMM #4, April 1987, we pointed out that Marshall McLuhan's dictum that "the media is the message," might be transposed to "the rocket is the payload." Of course, you can only push this so far. But this daring architectural philosophy offers the best way to escape the imagined, unnecessarily self-imposed tyranny of the mass fraction rule. "Of the total weight, 91 percent should be propellants; 3 percent should be tanks, engines, fins, etc.; and 6 percent can be the payload." – http://www.allstar.fiu.edu/AERO/rocket5.htm – we are not talking about exotic fuels or better rocket engines, but ways to include the 3% "tanks, engines, fins, etc." into the payload.

In the case of the Shuttle, the mass of the vehicle is much greater than the mass of the payload, so we do not come close to the ideal. At the time (the April 1987 article), I offered this simple example. In the shuttle space transportation system, the payload that gets to stay in orbit is a needlessly small portion of launch vehicle mass.



Adopting philosophy “the rocket is the payload” we could, if we so dared, deliver much more to orbit.



In the suggested alternative, the orbiter has a fore and aft section: Crew Cabin and Engine pod with much smaller wing/tail assembly. There is no payload bay. A much larger payload, with a lightweight faring if needed, takes its place. The External Tank is also placed in orbit as part of the payload. A stubby shuttle is all that returns to Earth. Savings include not just the payload bay section but the much lighter smaller wings and tail. The article referred above to is reprinted in MMM Classic #1, p 10, a freely accessible pdf file at:www.moonsociety.org/publications/mmm_classics/

Again, don’t waste time writing MMM with all the reasons this couldn’t be done. Instead, consider yourself challenged to figure out how we could do this anyway.

This is only one suggestion of how we can “cheat” the mass-fraction “rule.” The shuttle system will not figure in the establishment of a lunar outpost. So it is not these details, but the spirit behind them that we are trying to get across. Attitude, attitude, attitude!

Terracing the way back to the Moon

It seems unlikely that the Lunar frontier will be opened with vehicles that depart Earth’s surface, make the entire trip out to the Moon, and land on the Moon’s surface directly. So what we have to examine is all the various parts:

1. Earth surface to LEO (low Earth orbit) transports
2. LEO to Earth Moon L1 or Low Lunar Orbit ferries
3. Lunar orbit to lunar surface landers

At each phase, if the vehicle addresses the design challenges, material and/or useful assemblies and sub-assemblies can be deposited at the next. Whether it be all in one ride, or by a succession of waves, more payload gets delivered to the Moon’s surface, and/or more robust way stations are constructed in LEO and LLO (low Lunar orbit) or at the L1 Lagrange point. No oppor-tunity is missed. See “The Earth-Moon L1 Gateway” MMM #159, October 2002. You can download this issue freely:

http://www.lunar-reclamation.org/mmm_samples/

We would be remiss if we did not point out that one of the most brilliant components of the **Artemis Project**™ Reference Mission architecture involved just such a mass-fraction cheating device: reduction ot the portion of the landing craft that “returns” to the open-vacuum “space motorcycle.”

Micrometeorites strike the Moon, and space-suited astronauts!, on the surface, with velocities much higher than the velocity such a craft would need to reach lunar rendezvous orbit. It was the incorporation of this feature that allowed the Artemis Project™ ferry to deliver the relatively massive triple unit SpaceHab-based outpost core to the surface.

Whether the Artemis Project™ Reference Mission will fly as designed is not our topic and irrelevant. The point is that it demonstrates, at least in this instance, the kind of breakthrough paradigm-scuttling innovation that alone will get us to the Moon "to stay."

Stowaway Imports: smuggling more to the Moon

Another article we wrote that suggests ways to "smuggle" more useful material and items to the Moon is "Stowaway Imports" in MMM #65, May 1993. This article is republished in MMM Classics #7, freely downloaded at: www.moonsociety.org/publications/mmm_classics/

The idea here, is that it is inevitable that there will be structural, outfitting, or packaging items aboard craft landing on the Moon that are not needed for the return to the vehicle's base, be it in LLO, LEO, or Earth itself. The cost of getting these items to the Moon is prepaid as part of the cost of getting the payload consist to the Moon, whether or not they remain on the Moon or not. So if we leave them there, these items are a bonus.

Packaging containers, stuffing, dividers, etc. can be made of items not yet possible to duplicate on the Moon: some Moon-exotic element such as copper, or an alloy, some reformable plastic, biodegradable materials useful as fertilizers, nutritional supplements, whatever. Everything not absolutely needed for the ride back is game for scavenging. On crewed vehicles this can consist of everything from tableware to bedding, to appliances and even cabin partitions.

Some items can be thoughtfully predesigned for second use on the Moon as is. Others will be melted down or reformed for the useful material they contain. It's all free, or at least less cost than replacing them for the next outbound trip to the Moon. Only the "squeal" need return!

Designing moonbound craft to be cannibalized in this fashion will require resourcefulness, and exploration of many options, some more promising and less difficult than others. Stowaway imports are a way to supplement what personnel on the Moon will be able to produce or fabricate for themselves, thus leading to swifter development of a more diversified lunar startup economy.

Cargo craft landing on the Moon might be designed for one-way use only. Fuel tanks will be prize imports, landing engines may be reusable for surface hoppers. The idea is to build these craft cheaply and in numbers, much in the mold of WW II "Liberty Ships." If some crash or go astray, the loss will not be critical.

In our Lunar Hostel's paper (ISDC 1991 San Antonio, TX. we introduced the "frog" and the "toad" - Moon ferry under-slung crew cabins that could be winched down to the surface, lower its wheeled chassis, and taxi to the outpost: amphibious space/surface craft. The "frog" would return. The "toad" would be designed to spend the rest of its service life on the Moon as a surface transport "coach."

Modular Transportation

One of the more outstandingly successful innovations of modern transportation is the pod. Cargo in uniformly sized and shaped pods is transported on trucks, flatbed railway cars, and ocean going cargo ships.

The space transportation industry, especially the commercial sector, would do well to develop standardized pods, not waiting upon NASA clues which may never come, simply because the need does not arise in the very limited NASA lunar outpost mission plan. There may be more than one pod design, however, depending on the nature of the cargo. Liquids and aggregate materials (a load of wheat, for the sake of an example) may require container constraints, for shipment through the vacuum of space, that large assemblies do not.

The pod agreed upon would have significant repercussion for modular systems shipped to the Moon: modular power plants, modular water recycling systems; modular regolith processing systems; modular food processing systems; modular hospital cores; the list of possibilities is endless. No one size is ideal for all applications. However, we suggest that the current modular factory system serve as a model and size guideline, as it has proved remarkable successful. See MMM #174 April, 2004 "Modular Container Factories for the Moon."

Such a pod could also deliver inflatable to the Moon, which could then be outfitted on location, with cannibalized components and/or items manufactured by startup lunar industries. The result would be quicker build-out of the original outpost structure.

Transportation Systems Architecture Upshot

If we intend to expand the outpost into a real industrial settlement on an "inflationary fast-track" - the only way it can be done economically - the Earth-Moon transportation system must be so-designed from the gitgo, down to the last seemingly insignificant detail. A missed opportunity could spell the difference between success and failure. Our purpose in giving the examples above is less to fix attention to our examples than to get across the spirit. Spacecraft architecture, systems architecture, industrial design for reusability as is or with minimum processing effort, choice of materials, etc. And all vehicles at every stage should be designed this way.

Again, these lessons will be lost on NASA as its objectives are strictly limited: to deploy a moonbase in order to prepare for manned exploration of Mars. But commercial providers are likely to look for more exten-sive use of their products, for other more open-ended markets. It is with them that all hope lies. Those that adopt the above philosophy as a cornerstone of their business plans are more likely to survive and thrive long after NASA's government-limited goals are met.

II. An Expansion-friendly Modular Outpost Architectural Language, and Construction/Assembly Systems Design

This is one area in which the Russians and NASA with its various contractors, have already done considerable research and have acquired invaluable inflight/inuse experience in the Mir and International Space Station programs. Happily too, a commercial contractor, Bigelow Aerospace is now making groundbreaking contributions with inflatable module technology, borrowing heavily on NASA's Congress-aborted TransHab project. The prototype one quarter scale inflatable Genesis I is now in orbit and rewardingly performing well.

Modular architecture developed for the micro-gravity of Earth orbit will certainly have applications in the return to the Moon effort. It will apply directly to any way station developed at the L! Gateway point or in lunar orbit. But applications to the design of lunar surface outposts will need some rethinking for three reasons:

1. We are now talking about a 2-dimensional environment stratified by gravity, not the any-which-way dimensions of orbital space. The 1/6 Earth normal gravity environment mandates an established up-down orientation, no "swimming" through the air to get from one point to the other. This is minor.
2. Egress and ingress portals need to be designed to minimize intrusion of insidious moondust. It would be ideal if spacesuits were rethought with this challenge in mind, but NASA has already signaled its intention not to explore that route for money reasons. One more sorry instance of a "stitch in time, saves nine." NASA operations on the Moon will be far more expensive to maintain than the relatively trivial expense of wholesale spacesuit

redesign even at multimillion dollar expense. Commercial contractors may be the Knights in Shining Armor here as the NASA approach would be indefensible in any business plan.

3. Outside the safety of the Van Allen belts, radiation protection is required for more than short stays. The lunar surface station must be designed to sit under a shielded canopy, or to be directly covered with a regolith blanket. An added benefit will be thermal equilibrium.

While NASA, its contractors, and the Russians have a head start, it should never be assumed that they have explored all the options. Modular architecture is very much structured like a language: it has nouns (the various habitat and activity modules), conjunctions and prepositions (the various connector nodes), and verbs (the power system, the Candarm and other associated assembly and arrangement tools). The idea in constructing a "lunar-appropriate modular architectural language" is to come up with the most versatile, yet economic in number, set of modular components to support the most diverse and varied layouts and plans. The idea here is to maximize the options for expansion, without prejudging what needs will be accommodated first in the buildout.

We think that this concept is important enough to put to a design competition. NASA, contractors, the Russians can all advise on interface constraints and other design features that must be incorporated. Then let the would be Frank Lloyd Wrights of the lunar frontier have at it. We predict some novel suggestions that NASA and commercial contractors may want to adopt.

We has suggested in Part I of this article that modules should fit (yet-to-be-)standardized Earth-Moon shipping pods. The cheapest way of providing maximum elbow room, in the era before modules can be manufactured on the Moon out of lunar building materials, will be inflatable modules. Easy to deploy "outfitting systems" for these inflatable units are another area worth exploring through the device of an international design competition. The inflatable manufacturer can set the constraints which will include interior dimensions, purchase points, and ingress opening sizes. Then let the contestants exercise their varied inspirations.

Onsite manufacturability of needed components would be a design goal: maximum use of low-perfor-mance cast basalt, glass composite, and crude alloy items should be the preferred contest category. This way, expansion develops hand in hand with early startup industries, and becomes a strong incentive for their earliest development, saving substantial sums over importation from Earth.

Expanding on this theme, even equipment in hard-hull modules arriving fully outfitted from Earth might be limited to subassemblies of components not yet manufacturable on the Moon. A very simple example would be cabinets, tables, floor tiles, even chairs without horizontal tops or seats. These could be made of cast basalt, saving some weight in shipment. Many more possibilities of this compound sourcing paradigm are worth exploring: wall surfacing systems, simple utensils, appliance chasses, etc. See MMM #18, Sep. '88, "Processing with Industrial "M.U.S./c.l.e."

We mentioned the need for shielding. The development of simple canopy framework systems that can be locally manufactured, then covered with regolith, would be invaluable. Such canopies could protect stored fuel and other warehoused items that need to be accessed regularly, so that personnel could do these routine chores in less cumbersome pressure suits as opposed to hardened spacesuits. Such canopies could also serve as flare shelters out in the field at construction sites or at periodic points along a highway. An easily assembled (teleoperated?) space frame system with a covering that would hold a couple of meters (~yards) of regolith should be another design contest goal.

Modular Power Generation, Storage, and Heat Rejection Systems

This is a suggestion that NASA may well not bother considering. The initial outpost power generation and storage systems and heat rejection systems should be designed with modular expansion in mind. NASA will not be reflecting on the needs of expansion because its government mandate does not extend to expansion, unless space advocates force a change, even if “just to leave the door open for commercial developers who may follow.” We think such activism is worth the effort.

Introducing Load-based Modular Biospherics

In our opinion, NASA’s performance in developing life support systems has been hit and miss. Chances to incorporate a higher level of recycling on the Space Station were passed up in the name of up front economies, even though such systems will be absolutely vital on the Moon and Mars. To its credit, the agency does have the BioPlex project in full swing in Houston. But we worry that the outcome will be a centralized system that will work for the designed size of the lunar outpost, and not support further expansion.

The centralized approach to biospherics has a famous precedent: Biosphere II. We think centralized approaches are not the way to go. Instead, we should develop load-based decentralized systems. In this approach, wherever there is a toilet - in a residence, a workspace, a school, a shopping area, a recreation space, etc. there should be a system to pretreat the effluent so that the residual load on a modular centralized treatment facility is minimized. The Wolverton system is what we have in mind.

If all outpost modules with toilets have built-in pretreatment systems, then, as the physical modular complex grows by additions, the “modular biosphere” will expand with it. Expansion will not race ahead of the capacity of the contained biosphere to refresh itself.

Another essential element of modular biospherics is having plants everywhere. A phone-booth sized salad station will not do. Useful plants can be grown throughout the lunar outpost: they can provide additional salad ingredients and meal enhancers: peppers, herbs, spices, even mushrooms. Even decorative foliage and flowering plants help keep the air fresh as well as provide a friendly just-like-home atmosphere. Plants in front of any window or viewing portal would filter the stark and sterile barrenness outside.

Plants must not be an afterthought. We cannot long survive, let alone thrive as a species that hosts houseplants. We are a species hosted by the lush vegetation of our homeworld. We should never forget this. We cannot go with the attitude of “let’s build some cities, and a token farm here and there.” Rather we must go to build a new vegetation-based but modular biosphere which will then host our settlements.

City dwellers all too easily discount the farm. We have houseplants as botanical pets. That paradigm won’t work. Designing all habitation and activity modules to house plants as an integral feature will help allow the biosphere to grow in a modular way along with the physical plant. It will be a more enjoyable place to live as well.

NASA is unlikely to pay these suggestions a glancing thought. We hope that commercial contractors, whose long range plans are not limited by governmental myopia are more farsighted. Modular biospherics should be part of their business plans for any industrial settlements or tourist complexes on the Moon.

Teleoperation of construction & assembly tasks

So far we have been talking about architectural considerations that would prime any startup lunar outpost for expansion, no matter how restricted its mandated goals. But expansion, as well as original deployment, requires construction and assembly. To the extend that individuals in spacesuits are involved in this work, it will be dangerous and risky. Human manpower hours on the Moon will be expensive to support. Loss or incapacitation of just one person in an outpost construction accident would be a major and expensive one.

In order to maximize crew usefulness and productivity as well as health and safety as many tasks as possible should be designed for remote operation by persons safely inside the outpost or construction shack, or by teleoperation by less expensively supported people back on Earth. The latter option may be more technologically demanding but it is far more preferable. Every construction operation tele-controlled from Earth frees personnel on the Moon for things that only personnel on site can accomplish. The result is progress is surer, safer, and yet quicker. The outpost is up and running in less time, with everyone healthy and ready for real duties.

In the following article below, we take up this fascinating topic of pushing the limits of teleoperation, surely a prime area for engineering competitions.

III. Locate for local, regional, and global expansion options

NOTE: This is an area of some controversy, and this section of the article is not reprinted here. Basically, it is the opinion of a small minority, that the Moon's South Pole is the place to start. We feel that the advantages are overstated, the disadvantages minimized, if not ignored altogether. Those who foresee only Antarctic style operations, and those interested only in exploring the South Pole Aitken Basin will not be concerned about what advantages or disadvantages a South Polar site has to serve as a starting point for an eventual global lunar presence.

Teleoperation: getting the most productivity from our personnel on the Moon

By Peter Kokh

Tel•e•o•per•a•tion: the remote control of the operation of untended equipment; radio-control;

Actually "teleoperation" is a relatively new word coined by space development writers. Even though we have been using it for two decades or more, it has escaped notice by those who are supposed to keep dictionaries abreast of the times.

The basic idea is do what we can, remotely, on the Moon, when human on site labor would be expensive, or dangerous, or best reserved for things that cannot yet be easily remotely performed. What makes teleoperation practical on the Moon, but discouragingly tedious on Mars, is the speed of light that governs remote control by radio. At that speed, there is a bit less than a 3 second delay between a teleoperators "joy stick" movement and the observation of the command being performed. Numerous experiments, many of them by enthusiasts, have shown that this small time delay is manageable. On the other hand, anyone attempting to teleoperate a rover or some other kind of equipment on Mars would have to endure a minimum delay 125 times longer, 6 minutes, and a maximum of around 40 minutes. Ho hum! Zzzzz!

Equipment on Mars, a whole fleet of it, in fact, could indeed be easily teleoperated from Phobos or Deimos, but the Mars Society resists the idea of setting up forward outposts on either Mars moonlet, as a "detour." That's their problem. Impatience always bites one in the but, one reason the opening of Mars must be more broadly based. But we digress.

Proposals on the table for teleoperations on the Moon

Over fifteen years ago, it was suggested that mini-rovers on the Moon could be "raced" against one another over a prescribed course, the race watched on television, with the contestants paying for the privilege. The idea was to raise money.

More to the point, it has been suggested that equipment placed on the Moon could be tele-controlled to grade and prepare a site for a lunar outpost and once that was in place, the same or additional teleoperated equipment could cover it with regolith shielding, in advance of the arrival of the first moonbase crew. These would be time-consuming tasks for human crews. By tele-performing these operations, the crew would arrive at a Moonbase all set to go.

Beyond Site and Outpost Preparation

There will be "too much to do" for the small initial crew right from the outset. Nor will this change when the outpost begins to grow, not even when the first true settlers arrive. It is a truism of all frontiers, that there is always too much to do, that needs being done, than people to do it all. Sending people who are each multi-talented will certainly help. But that will not change the fact that there are only so many hours a day, and that there are limits beyond which driving individuals to put out ever more and more will backfire.

More to the point, there is a question of priori-ties. Some things are too sensitive and/ or too complex to be performed remotely. Hair-trigger responses are needed. On the other hand, there are tasks that are reasonably dangerous to perform, with a high risk of injury, or even death. These considerations give us a basis on which to decide when it is better to teleoperate, and when it is best to have an on site individual perform a task.

Add to that the financial considerations. Each manhour of work, regardless of the payscale, performed on the Moon, costs much more than that person's pay. You have to factor in what it cost to send that person to the Moon, maintain him/her there in good health, and to eventually (at least in the early phases of our open-ended presence on the Moon) return the person back to Earth.

It makes even more sense then, to find a way to teleoperate all risky and dangerous jobs, all routine and tedious jobs, and anything else we can do to relieve base personnel of any work we can so that they can get on with doing what only they can do. That way, the outpost, whether it is manned by four or forty or four hundred, can advance more quickly, will get more accomplished, thanks to its ghost army of teleoperators back on Earth.

Yes, we'd all like to see the lunar population to swell quickly to the hundreds, the thousands, maybe someday the hundreds of thousands. But doesn't taking jobs away from real people on location counter that goal? To the contrary, it advances it, because at each stage this pocket of mankind will be more productive, allowing it to grow faster, not just in industrial diversification and export output, but also in numbers. And the extra productivity earned by teleoperations, will make the settlement bottom line more attractive, less a target for budget cutters on Earth. When they arrive, their habitat space will be ready, thanks largely to teleoperated tasks.

What all can we teleoperate?

- Site preparation: grading, road building, excavation, shielding emplacement, repeatable construction and assembly tasks, deploying radio/microwave repeaters, deployment of solar power stations, initial prospecting surveys. (much more, especially in a given time, than Spirit or Opportunity can do), setting charges in road building, gas scavenging, preliminary routine prospecting surveys, lavatube exploration, etc. - i.e., many tasks that need to be done out on the surface, minimizing EVA hours by personnel in space suits.
- Tending agricultural installations: routine watering, weeding harvesting, fertilizing, etc.
- Many factory operations: especially dangerous ones
- Desk work: paper pushing, document processing tasks

The priority should be:

(a) Taking care of as many out vac tasks as possible which would be exhausting and cumbersome for people working in space suits, and not without real risk.
(b) Exploration of subsurface voids - lavatubes.
(c) Inside operations which carry some danger.
(d) Routine, repetitive, and boring tasks to the extent that they cannot be automated.
(e) Utility and air/water treatment routine tasks,
(f) Routine inspection jobs,
(g) Some bureaucratic paper work, minimizing the amount of desk work that has to be done on location.

(h) When the time comes, the bulk of routine teaching assignments. Again, one must keep in mind, that teleoperations are to prepare for humans to settle in and live comfortable fulfilling lives.

What we can do now

If we succeed in putting together an aggressive Lunar Analog Research Station program, one thing we don't have to do is prove the value of human-robot teams in field exploration. We have already made that point in the Apollo program years. So practicing lunar geology is not a high priority, nor is field exobiology. The M.A.R.S. analog stations have done great work in this area. Again, we've already made that point almost forty years ago.

Teleoperation with a 3 second time delay has been demonstrated many times, but mainly in the "driving" of rovers. More complex tasks such as site preparation and shielding emplacement via teleoperation have not been demonstrated.

These are challenges suitable for college level engineering teams, and the demonstrations could be done at an analog station. What we'd need for terrain, at least in the area where we would be teleoperating is a physical analog of lunar moondust or regolith. The elemental and chemical composition would be irrelevant. The mix of particle sizes and the behavior of the mix in handling would be essential. It would be in NASA's interest to fund creation of such a site, whether a sandy gravel mix native to the area was further transformed to meet the experiment constraints, or whether the faux regolith was prepared elsewhere and trucked in.

Once site preparation and shielding emplacement techniques were demonstrated, we could ramp up the challenges to include road construction and many other chores we'd prefer not to have done by humans in cumbersome spacesuits, exposed to cosmic radiation. Teleoperated exploration of a nearby lavatube would be possible in some of the sites under consideration (Bend, OR; El Mapais National Monument south of Grants, NM, Craters of the Moon National Park in Idaho). But we could run such tests at one or more of those locations whether or not we had an analog research station nearby.

We could also try to develop teleoperable greenhouse systems and waste water recycling systems; even though we don't need to demonstrate human geology field work, we could demonstrate teleoperation of pros-pecting probes. The possibilities are many, and will grow with the complexity of our outpost, and its continued growth.

Teleoperators on Earth

These people, whether unpaid volunteers, or paid assistants, should earn status as "lunar pioneers." For even if they never personally set foot on the Moon, the fruit of their work will be in evidence throughout the area where human settlements spread. **MMM**

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The Outpost Trap

THE OUTPOST TRAP

Technologies Needed to Break Free

By Peter Kokh

IV: ISRU, In Situ Resource Utilization

NASA's announced intention is to begin a modest program of ISRU, in the form of oxygen production from the regolith. A major problem with the plan has emerged, however: NASA is designing the Lunar Ascent Module to use fuels that do not include oxygen! Yet oxygen is not only needed for life support, if transported to Low Earth Orbit, it can be used on the next run out to the Moon, saving the major expense of getting oxygen-prefuelled vehicles up from Earth into LEO. We hope that NASA is not dissuaded from going ahead with its modest and limited ISRU project, however, as it will be just the beginning, the first step in using "on location" [Latin "in situ"] resources.

First, the basics

We need to begin with basics, such as **cast basalt** and **sintered iron fines collected with a magnet**. These can provide abrasion-resistant chutes and pipes and other items for handling regolith, and low performance metal parts respectively. Then we can handle regolith more effectively to feed additional ISRU projects.

Composite Building & Manufacturing Materials

Long before we can produce iron, aluminum, magnesium, titanium and workable alloy ingredients, we can make useful building materials out of raw regolith and minimally enhanced regolith-processing elements and building materials from the regolith. Using highland regolith with a higher melting point to produce **glass fibers**, and mare regolith with a lower melting point to produce **glass matrix** material, we can produce glass-glass composites on the analogy of fiber-reinforced resins (fiberglass). But to make this work we need to bring down the melting point of the mare glass matrix material further by enriching it with sodium and potassium. (A study funded by Space Studies Institute recommended the expensive import of lead as a temperature-reducing dopant!) This gives us an **action item:** isolating sodium and potassium, or sodium and potassium rich minerals.

If we can also isolate sulfur, we can experiment (and yes, why not here and now?) with fiberglass-rein-forced **sulfur matrix** composites. Simpler yet, we can make many low-performance household items from "dishes" to planters to table tops and floor tiles from crude **raw glass** and **cast basalt**, no processing needed other than some sifting.

We will bet that glass composites, sulfur composites, cast basalt, and raw basalt glass will all find profitable terrestrial applications which may make the predevelopment of these technologies attractive to entrepreneurs, thus putting at least a close analog of technologies needed on the Moon, "on the shelf," in a reverse of the usual "spin-off" sequence. We call this "Spin-up."

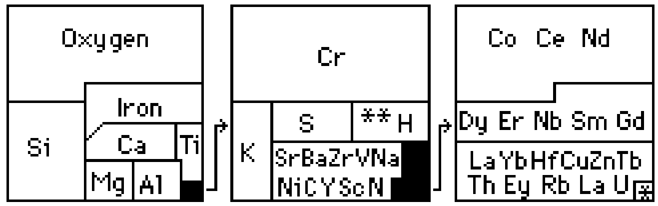
Metal Alloys

Using ilmenite (we can now map ilmenite-rich mare deposits on the moon) we can use this **iron**, **oxygen** and **titanium** mineral to produce all three elements. It is **the first ISRU Suite** to be identified. We need to identify more. Lunans will not live by oxygen alone!

Aluminum, abundant though it is, might be the hardest to produce, magnesium, somewhere in between. The catch is that for all four of these "engineering metals" the elements we regularly combine them with in order to produce workable alloys are rare on the Moon. For iron and steel we need carbon. For aluminum we need copper, and to a lesser extent zinc.

The action item here is for **metallurgists down here on Earth** to dust off old alloy experiment records. Some pathways, while doable, promised less superior results, and may have been abandoned. If they involved alloy ingredients that are economically producible on the Moon, we may have no choice but to go down that route to see where it leads. We need to do **research now** on lunar-feasible alloys that will perform in a "second-best" manner. Second best is better than nothing.

At a minimum, we need to be able to isolate, or produce, not only the four engineering metals, present on the Moon in parts per hundred, but all the elements present in parts per 10,000. See middle square below



Read: “Beneficiation” MMM #63, republished in MMM Classic #7
Read this NASA page also: http://ares.jsc.nasa.gov/HumanExplore/Exploration/EXLibrary/docs/ISRU/00toc.htm

Agricultural Fertilizers

From past NASA experiments with the Apollo Moon samples, we know that regolith has about half of the nutrients needed for healthy plant growth. Using **gas scavenging equipment** on board all earth moving vehicles (road construction, shielding emplacement, material for processing and manufacturing) we can use the harvested carbon and nitrogen and hydrogen to make fertilizer supplements. Potassium we will find in KREEP-rich deposits around the Mare Imbrium rim. Other elements hard to produce on the Moon can be used to manufacture cannibalizable shipping containers and packaging materials,to “stow away” on a ride to the Moon.

Let there be color!

Combine humidity, likely to be higher in pressurized habitat spaces, with the iron fines in regolith and we get rust for a splash of color. Titanium dioxide produced from ilmenite will give us white. Combine rust and white and we get a pink. Black, many gray shades, white, rust and pink. The rest will be harder. **Metal oxide pigments will be a secondary goal** in our processing experiments.

Using the Slag and Tailings

Slag and Tailings are in themselves “beneficiated” stuffs from which we can probably make many low performance household items and construction elements. Doing so will reduce the “throughput” of our young lunar industrial complex. By treating these byproducts as resources rather than as waste (“wasources”) we reuse the energy that was used to form them. This will work to greatly reduce what the settlement “throws away” - the goal being “nothing!”

Export Potential

Killing two birds with one stone has always been a desirable strategy. ISRU products from oxygen to metal alloy and non-alloy building and manufacturing materials will reduce the need for expensive imports as Lunan pioneers learn to make more of the things they need to expand their settlement and outfit it in a livable manner.

But for long-term economic survival it is essential to go beyond reducing imports. There will always be some things the settlement is no large enough, and its industries not sufficiently diversified to produce. There is a need to pay these imports. We cannot rely on any long-suffering generosity of terrestrial taxpayers. We can pay for our imports with credits from exports. Now in addition to proposed energy exports, and various zero-mass exports ranging from communications relays to broadcasting unique lunar sporting (and dance) events to licensing technologies developed on the Moon, there is an area of real material exports.

The Moon’s Primary Export Market is LEO and GEO

As long as one thinks of Earth as the Moon’s only trading partner, this prospect seems outrageous. Ship-ping cost would make lunar products very expensive. On the contrary, it is shipping costs that will be the settlers’ trump card, if there are other markets developing side by side in space. For example, while lunar building and construction materials and outfitting products may seem crude and unrefined to us on Earth, if they do the job, we can deliver them to low Earth orbit commercial space stations, orbiting industrial complexes, and orbiting tourist hotel complexes at a definite advantage over any competitive product that has to be boosted up from Earth’s surface. It’s not the distance, but the gravity well difference. For any product we make, as far as in space markets go, Earth will not be able to compete.

We have to think of the future economy as including not just Earth and the Moon, but other areas in nearby space that will become areas of human activity. This market will continue to work to the advantage of the rapidly diversifying lunar economy and growing lunar population as the population in orbit continues to grow, and as Mars begins to open up. It can only get better. But ISRU, not just of oxygen, but of many elements is the key.

ISRU and Rare Elements on the Moon

Dennis Wingo, in his recent book Moonrush, sees the Moon as a potential source for platinum needed for fuel cells to make the forecast Hydrogen Economy work. None of the samples returned by the six Apollo landing missions and the two Soviet Lunakhods showed this element to be present in parts per billion. Now you can say that we only sampled eight sites. Not quite true when you consider that at any given location on the Moon, only half the material is native, the other half having arrived as ejecta from impacts elsewhere on the Moon. In that sense the areas of the Moon samples are somewhat represen-tative. Wingo argues that platinum-bearing asteroids had to have bombarded the Moon. We do not quarrel with that. But it is likely that the infinitesimal smithereens are scattered all over the place with no enriched concentra-tions anywhere. Now we'd be happy to be proven wrong.

Geologist Stephen Gillett, University of Nevada-Reno, and an expert on lunar geology, now thinks that the way to beneficiate (increase the concentration of) scarce elements is to feed regolith to bacteria in vat cultures, the bacteria having been bioengineered to feed preferably on given elements.

Dr. Peter Schubert of Packer Engineering in Naperville, Illinois outside Chicago, has developed an on-paper process, patents pending, that would use shoot regolith into a 50,000 degree (C or F?) laser beam and separate out the various elements and isotopes and direct them to separate catching containers. This is, of course, the ISRU process to end all ISRU processes. We are not qualified to estimate what is involved in develop-ment of a working demonstrator, or at what scales this process would operate most efficiently. It does seem to require a considerable energy input, perhaps from solar concentrators. It offers a glimpse of a future, in which lunar settlements are shipping megatons of sorted elements for construction projects in space

Summing Up

- √ We cannot thrive on oxygen production alone! We need to concentrate on other ISRU goals, especially **ISRU Suites** or Cascades in which more than one element results.
- √ We need to enable with **research now**, early industries that fill needs and defray imports – Building, Construction and Manufacturing materials
- √ We need better, **higher resolution global lunar maps**, that show not just where we will find regolith enriched in iron, calcium, thorium, and KREEP (what we have now, at least at poor resolution.) We need orbiting instruments to indicate the richest concentrations of other elements we will surely need. Action item: suggest to NASA in detail, the kind of instruments it should fly on planned orbiters.
- √ As this information comes in, keep **reducing the long list of settlement locations to a short list.** What we have noted already, demands, If we truly want lunar industries and industry-based settlement, to look elsewhere than the highland-locked poles. What we need is a Highland Mare Coast, near ilmenite and KREEP deposits. That would give us access to all the major and most of the lesser abundant elements present on the Moon. But we may have to establish a number of settle-ments, each in differently endowed locations. After all, one settlement does not make a world!
- √ We must **research reuse options** for pre-beneficiated tailings as building materials with lesser performance constraints. On Earth, there is no shortage of abandoned piles of tailings with which to experiment. Entrepreneurs, like artists, love free materials.
- √ Many experiments are possible with **obvious terrestrial applications** which may prove profitable.
- √ We need **an organizational machine** that will

- Work to identify all these research needs and
- Attract effective attention to them
- Serving as a catalyst to get the work done.

√ The goal, if we choose to accept this mission, is to return to the Moon, ready to start building out the first resource-using settlement, so that the NASA Outpost can do science for a while, then retire to become an historic lunar national park site. In short, our goal is "Escape from the NASA Outpost" - returning to the Moon with the tools needed to avoid the "Outpost Trap."

V: Industrial Diversification Enablers

1. Accepting the dayspan-nightspan energy challenge

It is not enough to develop the technologies needed to turn on location resources into products for domestic use and export. We have a little quirk in the way the Moon does its own business, rotating in and out of sunlight every lunar "day" that presents a considerable challenge. The Moon's "day" is almost 30 times as long as the one we are used to.

The challenge is to find ways to store up as much energy as we can during the 14.75 earth-day-long dayspan as potential energy, to keep us running on a lower but still productive level through the 14.75 earth-day-long nightspan.

Yes, that's why so many lunar advocates a drawn like moths to the eternal sunshine of very limited and rugged areas at the Moon's poles. But if you read the last two pages, you will know that except for water ice, the resources needed to build an industrial lunar civilization lay elsewhere. We will have to ship the ice to the settlements just as we ship the oil from Alaska's north coast to California.

There is no way to avoid taking on the dayspan-nightspan challenge. Turn aside from the challenge and we may be limited forever to tiny ghettos' at the lunar poles. Accept and win the challenge, and the Moon is ours, all of it.

The options for dayspan storage of energy to use during nightspan are treated in other articles.

See: MMM # 126 JUNE '99, p 3. **POTENTIATION: A Strategy for Getting through the Nightspan on the Moon's Own Terms** - This article reprinted above.

2. Accepting the reduced nightspan power challenge

We might think of the pioneers waiting out the two-week long nightspan playing cards, writing their memoirs by candlelight, and making love for want of something else to do. But if we successfully meet the dayspan power storage problem, the pioneers will have enough energy to continue being productive by focusing and concentrating on less energy intensive and perhaps more manpower intensive tasks and chores, leaving manpower light and energy intensive processes for the dayspan. Inventory, scheduled maintenance, product finishing, packaging and shipping, etc.

The challenge is to take every operation and sort it into the two kinds of tasks or steps stated above. Not every industry is going to lend itself easily to an equal "division of scheduled labor." Some will need more manhours during the dayspan and have few assignments to keep as many people busy during dayspan. Other industries may present the opposite situation. One can see arrangements where some employees work for company A during the dayspan and company B during nightspan.

Can we come to a plan whereby everything evens out and everyone is kept busy all "sunth?" (the Sun appears to revolve around the Moon once every 29.53 days, whereas the Earth does not, i.e. sunrise to sunrise marks the period we know as new moon to new moon, "month" for us, "sunth" for them. I digress. We have stated an ideal a lot of trial and error and the steadily increasing diversification of lunar industry predicts an ever-shifting employment situation. Our purpose is to suggest the process management research that we need to undertake now, industry-by-industry, business by business if we are to have any hope of making ourselves “at home” in the lunar dayspan-nightspan cycle. At stake is the success of lunar industrial diversification, and the competitive market cost of lunar export products.

3. Accepting the radiation challenge

“The Moon is a Harsh Mistress,” blares the title of one of Robert A. Heinlein’s best-known science-fiction novels. Part of that harshness comes from seasonal solar flares of great intensity. Part of it comes from incessant cosmic radiation from all quadrants of the sky. Part of it comes from the Moon plowing through space rivers of meteoritic dust left behind by comets.

All of these dangers call for shielding. The most used lunar resource of all is going to be plain regolith, piled up above habitation and working spaces, directly, or indirectly, that is over hanger-type frames with habitat structures and vehicles safely inside.

We understand the challenge, and the many options. We are prepared to meet the challenge for people in place. But what about for people in transit? A solar flare can hit the Moon with insufficient warning to allow vehicles more than a few minutes from base to return in time.

We need to give attention to the architecture and building systems to deploy at the least expense, effective wayside flare shelters at regular intervals along roadways. Whether they are lightly or heavily traveled makes a difference not in the spacing and number of shelters, but in how capacious or large such shelters are.

The Moon, like any new frontier will remain hostile and unforgiving only until we have mastered the ways of dealing with the new environment as if by second nature. The need to quite literally cover our butts from the rare but hard to predict solar flare is one we must take seriously. Lunar industry must anticipate this need.

Working out-vac in spacesuits will be cumbersome and tiring. For routine tasks such as accessing out-vac utility systems or outside storage items needed on a regular basis, it would make sense to place all these items under a shielded unpressurized hanger, shed, or canopy. Then a lightweight pressure suit will do, and that will greatly reduce stress, fatigue, and discomfort. The architectural systems for this everyday out-vac shelter system are the same as those needed in the event of solar flares. We can meet this need now by university-level architectural and engineering competitions, with ease of deployment and of shielding emplacement above the frame all being part of the challenge.

4. First industries first

It will be a challenge in itself, just to decide which industries to deploy first and just which of many possible paths lunar industrial diversification will take. As in picking a college course, one has to give attention to “prerequisite” courses. Likewise, some industries presuppose others in place beforehand, and in turn enable yet additional industries. Some industries will be viable only if developed side by side, step by step. Now there’s a doctoral thesis for someone!

We make no pretense of being able to sketch such a tree of industrial ancestors and descendants, but would like to start with some notes about what we need to break out of the Outpost Trap. Rather than repeat, we ask the reader to take a second look at MMM # 91 Dec. 1995 p 4. “Start Up Industries on the Moon” - reprinted in MMM Classic #10, a free download pdf file at the sites listed above. Also MMM # 191 DEC. 2005, p 7. First Lunar Manufacturing Industries - available as a Moon Society username/password accessed directory of recent MMM pdf files; www.moonsociety.org/members/mmm/

But, first things first!

- regolith bagging and other regolith shielding systems enhanced
- prioritization of fabrication of furnishings and outfitting needs for inflatable modules
- using those same industries to fabricate things for residential quarters.
- Some early art and craft media to make ourselves feel at home with art expressed in native materials

5. One Size does not fit all

In last month's installment, MMM #198 page 4, "Modular Transportation" and following, we mentioned that importing modular factory pods and utility pods made sense. That said, a system that works on the scale of a "Semi" trailer, may not be the best choice for a smaller installation, nor for a settlement that had grown considerably. We need to base our judgment of system efficiencies and production on scale-dependent guide-lines. For a tabletop demonstration, one ISRU device may work fine, but fail utterly on a much larger scale, and vice versa.

6. Attitude is the make-or-break ingredient

If your way of operating causes a problem, you are unlikely to contribute to a solution. At every stage of human advancement, there have been shingle-qualified experts who have said this or that could not be done. A favorite trick in teaching students how to handle such situations is to ask them to jot down all the reasons such and such is impossible to achieve, and then, after they have done so, give them a second assignment: "Now right down all the reasons why we are going to do it anyway."

We have to bypass stuck-in-the present experts and luck for "Young Turks" with an open and aggressively adventurous curiosity, determined to find workarounds and new pathways where none were suspected before.

The Moon will be one hard nut to crack. I am sure a human ancestor in Africa a hundred thousand years ago, suddenly transported to the northern coast of Greenland would have thought the same thing. But we did crack that nut. The Innuit and Eskimo take living under such conditions for granted. They handle the challenges that would be life-threatening to us by second nature.

If we get raised eyebrows along the way, "industrializing the Moon, are you?" let those raised eyebrows encourage us all the more. The epic sweep of the human saga from Africa to continents beyond the shores of their home continent/world runs through our veins. We will do this, because we are humans. And as before, we will become even more human in the doing of it. For the challenge of settling the Moon will bring out new capacities in us, capacities we did not know we had, because we were never challenged before to rise to occasions such as lay before us. **MMM**

MMM # 201 - DEC 2006

M O D U L A R

B I O S P H E R I C S

Making the most of pressurized pedestrian & vehicular corridors:

"Living Wall Systems"

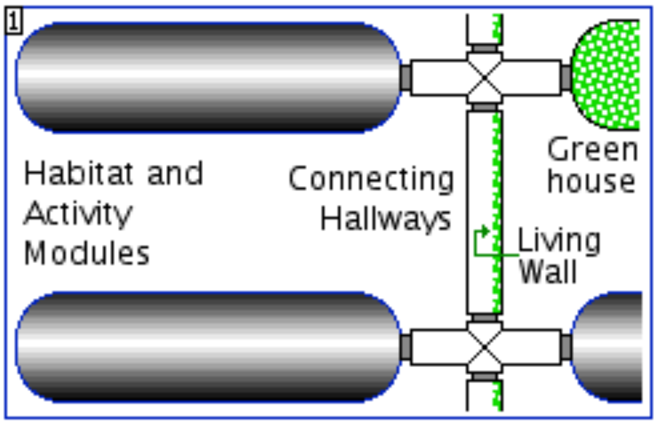
By Peter Kokh

"A **living wall** is a vertical garden. Plants are rooted in compartments between two sheets of fibrous material anchored to a wall. Water trickles down between the sheets and feeds moss, vines and other plants. Bacteria on the roots of the plants metabolize air impurities such as volatile organic compounds." http://en.wikipedia.org/wiki/Living_wall

While this is the definition in the most technical sense, experimenters have made living walls in which plants are in pots anchored to a wall in a staggered pattern. They have also found other ways to keep them properly watered, fertilized, and to recycle the drainage water. In a modular outpost, there will be connecting tubular passageways for pedestrians and small carts. Their curved walls offer an opportunity to increase the overall biosphere mass of a lunar outpost (real or analog) by integrating a living wall feature along one side, for the whole length of (each) hallway. This will be in addition to the biomass contributed in any Greenhouse modules and any in the habitat and activity modules themselves.

In a larger settlement, pressurized roads could have living walls to each side, and, down the middle, to separate traffic flowing in opposite directions, boulevard style.

If we continue to think in terms of floor space, then we will be put in competition with the plants we depend on – not a prescription for success. But plant areas can make use of otherwise empty wall space.



Right above: Cross-section of a hallway corridor in a modular Lunar Analog Research Station – or in an actual Lunar Outpost

"Waste no opportunity to include more plant life, want not for your next breath" to paraphrase an old saying.

If we are talking about an open-ended installation (again, either on the Moon or at an analog research site) by adopting a policy that no wall should be idle, we guarantee that the modular outpost grows, a modular biosphere grows with it, neither outstripping the other. Now can there possibly be a better arrangement?

Yet so far all biosphere experiments seem to be of set size, not designed to grow in modular fashion. The non-modular set-size approach tends to be an effective predictor that the installation will have no future.

Right above: Living Wall installation, Baltimore, MD. This 110 sq ft (10 sq m) wall filters all the air for its 7,500 sq. ft. office building. Notice the ornamental character of some plants chosen
Decorative Options: It is easy to work in rocks and planters, sculptures and other objects into a living wall system. These can be design accessories or fully functional parts of the plant holding and water irrigation systems.

from **www.verdirsystems.com/html/living-walls.html**

The above shows a technical approach.

Dr. B. C. Wolverton, doing the research for NASA, identified a dozen common house plants easily available that cleansed the air, including: gerberra daisy, bamboo palm, spider plant, marginata, mass cane, spathiphyllum, Janet Craig, and English Ivy - published in the pamphlet "Plants for Life: Living Plants Vital In Filtering Contaminated Air"- a NASA pamphlet published more than fifteen years ago.

Now Dr. Wolverton has published a much more comprehensive treatment in the book,

"**How to Grow Fresh Air: 50 Houseplants that Purify Your Home or Office**"

Penguin Books ISBN 0.14.02.6242.1.

Many Living Wall installations use a system of staggered planters and integrated water features to accomplish the same ends in a more natural and beautiful fashion.

Plants to choose from

There is a wide variety of plants that provide lush green foliage while cleansing the air of toxins (to prevent "sick-building syndrome") and increase the amount of oxygen, maintaining a fresh, clean atmosphere inside.

Living Walls as Graywater Purifiers

www.holon.se/folke/projects/openliw/openlev_en.shtml

"By growing plants in a porpos wall [a special adaptation of the Living Wall concept, read on], you get both an efficient space use by vertical plant growing and purification of the percolating water, which can be grey-water." (Graywater is water from sinks, tubs, and showers, and previously treated blackwater from toilets.)

"The hollow parts of the stones are filled with inert material, like gravel, LECA-pebbles, perlite or vermiculite. The stones are placed so the water will percolate in zigzag through the wall. Bacterials in the porous material break down organic pollutants. The water trickling down through the wall will nourish the plants at the same time as it will be purified The plant roots will grow into the inert material and extract nutrients from the water. Over the pebbles, a bacterial film of will grow. After comsuming organic material they release the nutrients in the percolating water. The plants will take up the nutrients and subsidize the bacteria with sugar from their photosynthesis.

"By this, you get both vertical growing & grey-water purification. Therefore, the efficiency of the purification is dependent on the amount of solar radiation reaching the plants in the wall."

Air Circulation Systems

"Active walls'" are also integrated into a building's air circulation system. Fans blow air through the wall and then recirculate the refreshed air throughout a building. These indoor living walls help prevent and/or cure what is known as "sick building syndrome" by increasing air oxygen levels.

Integrating Water Features and Fish

Some Living Walls integrate fish ponds at the foot of the wall as part of the system where trickling water collects before it is pumped back up to the top of the wall.' The foliage purifies the graywater, digesting the dissolved nutrients. Thus a living wall can be an integral part of water purification and reuse, not just fresh air.

A living Wall is something to be designed to suit taste as well as to serve function. In a modular (analog or real) lunar outpost, each hallway could boast its own design, creating a more interesting working an living environment as well as a fresher, cleaner, healthier one.

You can go high-tech, but this is not necessary, and the cost-benefit ratios of a high-tech approach are probably not great. Low tech is always better if it works.

Using all Opportunities to increase biomass

We tend to make the mistake of describing living space volume in terms of square footage of floor space only, neglecting the opportunity walls provide. Counting all surfaces is the secret of packing a bigger biosphere into a smaller space: using walls, and even ceilings!

It is important, if we are going to bring the biosphere truly inside, to build our environment with mold-resistant surfaces. This means giving careful consideration to materials and surface coatings, as well as due humidity control and ventilation.

Sunshine, or its equivalent

Light must be brought in by light pipes, clerestories, or grow-lamps: a separate, related topic.

Purposes of a System of Living Walls in an Outpost

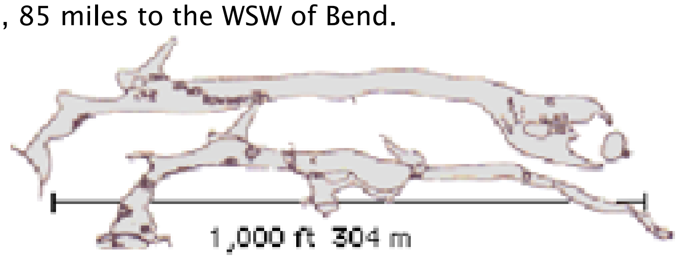
- Purify and freshen air; purify graywater
- Provide lush greenery, color, interest
- Provide herbs, spices, berries, etc. and last, but not least, to
- **Psychologically "re-encradle" crews in a mini-biosphere** ##

Use of Terrestrial Lavatubes in a Lunar Analog Research Station Program

By Peter Kokh

In August 1992, I had the wonderful experience of a personal guided tour of the pair of lava tube caves outside Bend, Oregon that the Oregon L5 Society was using for outpost simulation purposes. My guides were Bryce Walden and Cheryl Lynn York of Oregon L5.

Oregon Moonbase Photo taken during a simulation. The PVC tube frame would be covered with a tarp to serve as a makeshift base for students. The cave floor is flat due to the invasion of volcanic ash from the explosive eruption of Mt. Mazama 4,800 BC that formed the jewel known as Crater Lake, 85 miles to the WSW of Bend.



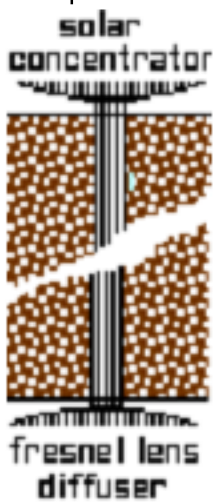
Above: Young's Cave complex outside Bend, OR.

Lavatubes on Earth are much smaller in scale than those on the Moon, probably in some inverse relationship to gravity. The widest portion of the Young's Cave complex is 79 ft., the greatest ceiling clearance 26 ft. but these dimensions are uncommon. Because of their much smaller scale, they are hardly simulation stand-ins for those on the Moon. But we can put them to some use. And on July 20, 1989, NASA granted the Oregon chapter $25,000 to do a thorough site characterization.

The Geological survey was done by Stephen L. Gillett, a consulting geologist now in Carson City, Nevada with U-NV-Reno. Century West Engineering of Bend did the engineering analysis. A series of 5 borings, in roomy locations specified by Oregon L5, showed the roof to be generally from 10 to 20 feet thick with 7-19 ft of hard basalt overlain by 0-3 ft of loose soil. Except for a few transverse cooling cracks, the ceiling is relatively intact and rock quality analysis shows the roof could support from 2-60 tons suspended weight per linear foot, depending on varying roof thickness and the presence presence or absence of fractures. For this, a system of rock bolts will do. In weak areas, roof-shoring supports are advised. Some 6000-7500 cubic yards of sand forms a floor 0-6 ft thick. This could be removed, if desired, by vacuuming. Rock debris could also be removed, if desired, by backhoe or by hoists through openings made in the roof, thereafter available for installation of equipment. But creating such openings whether by blasting, jackhammer, or rocksaw would be a major undertaking. The variations in surface terrain were also surveyed.

The estimated cost of preparing the site as a major lunar analog facility as outlined by the Oregon Moonbase team was over $6 million 1990 dollars. The Phase II grant never came. Eventually, the chapter decided to let the renewable 5-year lease on the facility expire.

But on the basis of what we learned about this pair of lavatubes during the study, we think that this facility, if we could regain access, or a similar tube elsewhere, could support unique simulation exercises. If the main moonbase facility was up on the surface nearby and only limited simulations done in the lavatube, the cost could be significantly lower, with a very modest initial presence expanded on a pay-as-you-go basis.



The five 60 mm (2 3/8") bore holes through the tube roof-ceiling could be used to drop in miniaturized survey equipment designed to demonstrate how we can robotically map the interior of lunar lava tubes, profiling their complex shapes and cross-sections. These tests finished, the bore holes could be filled with fiber optic bundles to let in sunlight concentrated up to thirty times. One bore hole could be used for communications access

A small Habitat complex could be put together out of small inflatable units or of EZ assemble-disassemble semi-prefab structures. At such a facility, where, within the lavatube, lighting would be totally controllable, we could more easily simulate the lunar dayspan/night-span cycle. We could examine ways of dealing with the two week long nightspan that would let a crew remain productive throughout. We would try to determine hwlittle power we could get by on and still be productive, concentrating on repairs, maintenance, inventory, and other power-light, manpower-intensive tasks, so as to better use the 15 days of dayspan solar power available to store up power to tap after lunar sundown.

Meanwhile, a nearby surface conventional outpost complex would investigate and demonstrate other things: teleoperations; in situ resource utilization; shielding options; and many more lines of investigation. While it would be ideal for the companion analog surface outpost to be very close to the lavatube entrance, a separation of a few miles should not hinder operations. Crew would go from one to the other in a “pressurized vehicle.” This allows room for latitude if it is not possible to have both outpost components closely collocated.

If the access to the Bend, Oregon site can’t be recovered, we might do something similar at lavatube locations at Craters of the Moon National Park, ID; El Mapais National Monument, NM; or Snow Canyon State Park, UT. The advantage of Bend is that the lavatube complex there is well known and studied, and familiar to a number of Moon Society members. **MMM**

MMM #202 - FEB 2007

M O D U L A R

B I O S P H E R I C S

Middoor Public Spaces as ideal Opportunities for added vegetation and even “urban” wildlife

“Middoors” MMM speak for pressurized common spaces such as pedestrian passages, streets, parks, and plazas where temperatures could be allowed to fluctuate between cool predawn lows and warm pre-sunset highs; as opposed to “indoor spaces” in private residences and in commercial, educational, office and Other fully climate-controlled areas of activity.

In the December 2006 issue of MMM # 201, we described Living Wall systems which take advantage of frequently unused or underutilized wall-hugging spaces for growing plants that will help cleanse indoor air of carbon dioxide and other airborne pollutants, boost fresh oxygen levels, and in the process create water features that could harbor fish. In this installment of our “Modular Biospherics” series, we take up the opportunities for additional vegetation in other common spaces within the outpost or settlement.

Public Squares, Plazas, Marketplaces, etc.

These will be enlarged nodes or pressurized intersections where three or more pedestrian passages and/or pressurized roads restricted to bicycles and electric vehicles come together. At least some of these intersection nodes should be enlarged to provide extra ground space for plants of various kinds, walkways, park benches, water features, etc. They should offer two more perks: higher vaulted ceilings, and over-illumination.

Higher ceilings offer welcome eye relief. The human eye has evolved to take in the sky, not just a horizon-hugging layer of vertical space. Living inside the confined vertically challenged spaces of an extensive modular maze will leave much to be desired. Yet, on the Moon at least, this may be necessary. The nitrogen needed as a neutral oxygen buffering component of breathable air will be in short supply. There are two ways to conserve the amount of nitrogen needed, and we will need to make use of both!

- Use one half normal air pressure, with all the hit being taken by nitrogen. That means, instead of a 79:21 nitrogen-oxygen mix, we may be using a 58:42 mix, with the actual partial pressure of oxygen unchanged. An important beneficial effect of using an 0.5 ATM pressure is that this will greatly reduce the propensity to spring leaks.
- Keep ceiling heights, and thus total volume of air needed, on the low side. I wouldn’t suggest lower than 9 feet. That may seem generous, but we would be allowing for the progeny of the first settler generation to grow taller than their parents, given the low gravity.

But here and there it will be advisable, for the sake of morale, to have more spacious places in which to congregate and relax. Outdoor full sunlight level lighting and notably higher ceilings, painted a matte sky blue and brightly uplit, will subconsciously lift spirits and supply a well-needed boost. People will enjoy being there!

We have ample experience creating little urban oases for people to relax and congregate. A hard-won lesson is that as great as has been the clamor for quiet spaces apart from the hustle and bustle of life, the experience has been that such places remain almost empty, favored only by a few. In contrast, urban oases in the midst of the hustle and bustle are always the more popular. Put simply, more people enjoy relaxing where they can see and be seen. We are, after all, social animals.

Big or small, such openings in the otherwise space-stingy modular maze of settlement outposts, they can be much greener if the vertical surfaces around the perimeter and vertical half-wall dividers within it, are given to wall-hugging narrow trees or shrubs, or better to living walls as described in our last issue. As dividers, living wall systems can easily be configured in 2-sided fashion. Using the "hanging gardens of Babylon" approach, more floor/ground space is available to paving tiles, seating, water features, and sculptures.

If the space, say a plaza in a prospering, growing settlement, is large enough, it may contain building structures playing supporting roles: changing space for performing artists, storage space for merchant kiosks, etc. These structures may also provide more vertical space to be given to living walls, and their roofs can be greenspace as well, so that the building in effect does not diminish overall ground space given to plantings. Roof top tea gardens would be popular, creating elevated spaces from which to watch passersby, and other activity on the main level.

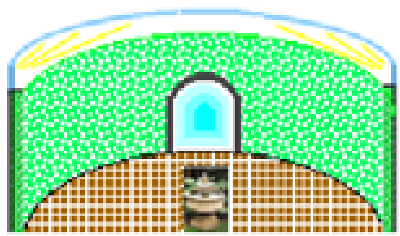


Illustration of a simple and small "greenhub" node, an intersection of 3 or 4 pedestrian passageways. It sports a higher vaulted ceiling, painted a matte sky blue, with cove uplit with bright sunshine spectrum bulbs. Vertical surfaces are living walls. The floor is of brick pavers or cobblestones, with a scattering of benches, flowerpots, and a central fountain. Connecting pedestrian walkways are lower in vertical scale.

Enter the polinators

It is amazing how many people do not realize that plants come in male and female also. Be that as it may, we do need to provide for plant pollination. Bees might be confined to agricultural areas, with only persons not allergic to their sting working in those areas.

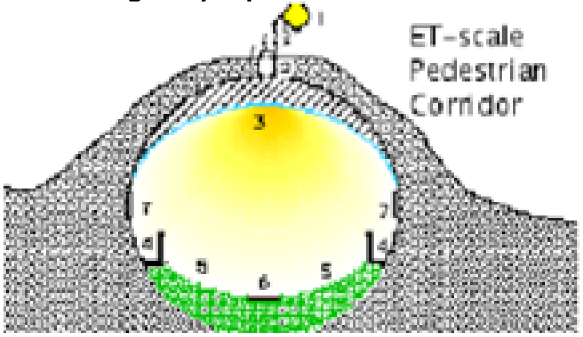
Hand pollination would be an unacceptable use of available manpower. Especially for agricultural areas, where similar plants are side-by-side, robotic hand-pollination equipment teleoperated from Earth where real labor costs are much lower, should be a priority area for research and development, with a lot of "spin-up" potential. In the meantime, we might concentrate on plant species that can be pollinated by hummingbirds. The sight of these tiny and beautiful creatures flitting to and fro in search of pollen syrup would do much towards making such urban relaxation spots all the more delightful. Might lunar hummingbirds slowly evolve larger subspecies? A hummingbird whose linear dimensions are 1.817 times Earth-normal for hummingbirds would weight as much on the Moon as our varieties do here.

We might make room for additional wildlife. Fish such as talapia, small tropical goldfish, even stream trout should mix well. But without adding in a mix of flying insects at great risk to serve as food, we'd have to feed them manually, or by automated fish-food dispensers.

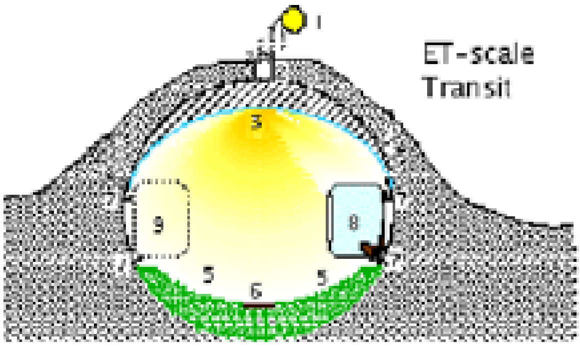
Squirrels and chipmunks can do much damage, but they sure are delightful to watch. The same is true of rabbits and other small mammals. If only neutered individuals were released into the settlement commons, and breeding stock kept strictly sequestered, runaway populations could be avoided. Humans evolved side by side with plants and animals. Sure, some individuals would sooner be without them. But how truly "human" are they? We need to go into space as the front wave for Earth life at large. We just have to be careful what species we bring along with us. But that's a whole new article.

If we are living, working, shopping, recreating, and traveling in pressurized spaces, there is no justification for any of these modules to be sterile, devoid of life. In our own cities, the boulevard is an icon for how pressurized roadways can be designed to contribute both to overall biosphere biomass, and to bio-diversity. Given the controlled climate, vehicles operating solely in pressurized environments can be open, roofless, and even open-sided. Of course, vehicles meant to operate at high speed would need wind-shielding.

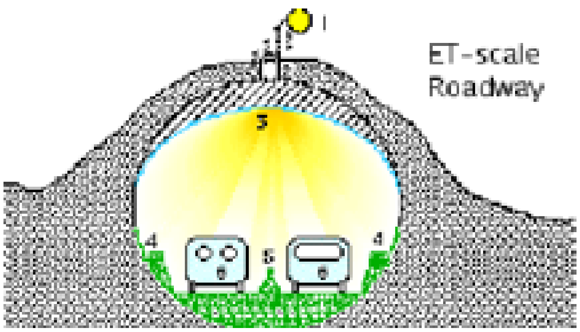
Various Larger Pressurized Passageway Options



KEY: (1) Sun, (2) fiber optic bundle sunpipe, (3) sky-blue sunlight diffuser (same pressure either side), (4) pedestrian walkways, (5) terraced plant beds, (6) gardener's path, (7) art & poster gallery



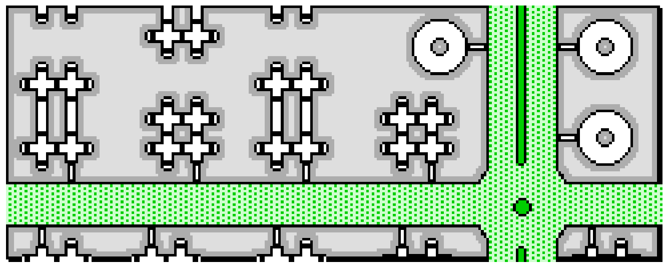
KEY: (1, 2, 3, 5, 6) as above. (7) wall-mount rail suspension system, (8, 9) bench seat transit car.



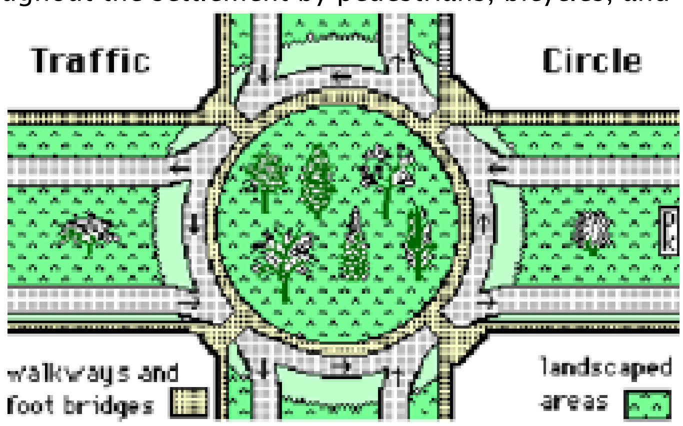
KEY: (1, 2, 3) as above. (4) living wall / hanging garden, (5) planter-topped divider, (6) vehicles.

In all of these connector examples, there is a place for vegetation, and the more place the better. It is more than a matter of morale, the comfort of mothering greenery against the stark sterile barrenness beyond the settlement airlocks.

It is a matter of always paying heed to the overriding requirement to maintain a healthy and integrally functioning biosphere as a host to all other activities within the settlement hull complex.



ABOVE: a sketch of how a residential settlement "block" grid could be laid out. The Green represents the pressurized road grid and its significant contribution to the total biomass of this modular settlement biosphere. One road is shown in boulevard fashion, with an expanded roundabout intersection centering on a tree & shrubbery inner circle. The gray represents the open-to-vacuum regolith covered surface. Shown in it, are various modular residences, individually regolith-shielded, all opening onto the pressurized road grid. This allows shirtsleeve travel throughout the settlement by pedestrians, bicycles, and electric vehicles.



More on the Settlement's pressurized road grid

There is considerable discussion of many aspects bearing on the topic of public places in the lengthy article "**Luna City Streets**" MMM #109, October 1997, pp. 3-11. This article has been republished in MMM Classics #11, pp. 61-69 – a free access **pdf** file download from:

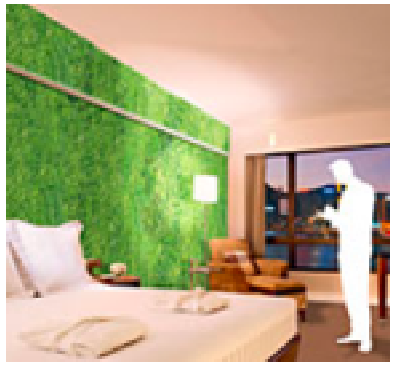
www.moonsociety.org/publications/mmm_classics/

MMM # 204 - APR 2007

MODULAR BIOSPHERICS

By Peter Kokh

I. Living Wall Systems, Continued from MMM #201 We recently found this excellent example to share.



[credit: Phillips & Co.] **A wall that breathes:** Envisioning some backlash against high-tech surroundings, designers conceived a back-to-nature hotel room with a lush "living wall" of grasslike vegetation. The wall, with a built-in watering and lighting system, would serve as an air filtering.
Reference: www.usatoday.com/travel/hotels/2005-05-05-hotel-of-tomorrow_x.htm

Toilet-equipped Habitat & Activity Modules – Wolverton or alternate black water pretreatment systems

The organizing idea of "Modular Biospherics" is to distribute biosphere maintenance functions throughout a growing modular physical complex. This philosophy obliterates the "single point of failure" biosphere catastrophe scenarios to which any centralized system or complex of systems would be inherently vulnerable.

It is also a biosphere architecture that grows naturally as the physical complex of the outpost/settlement grows. The size of any "problems" that must be tackled in central, or neighborhood treatment facilities is greatly reduced. Modular Biospherics greatly reduces both the scope and the frequency of "growing pains" crises.

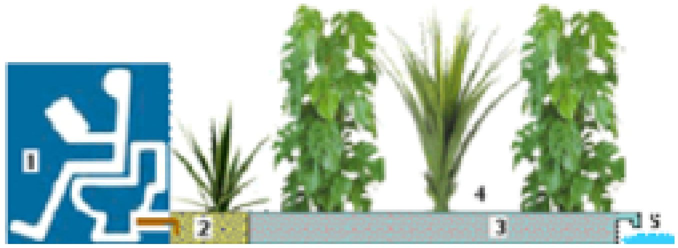
By distributing are and water treatment systems, biosphere maintenance becomes a democratic process: it is everyone's concern, and the immediate local consequences of neglected systems affect most those who are guilty of the neglect. We take Earth's immense biosphere for granted (up until recently, anyway.) On the Moon, the health of the minibiosphere of each settlement complex must be everyone's business or catastrophic failure will only be a matter of time, and will come sooner rather than later.

Living Wall Systems are designed to refresh air throughout the complex, with only local maintenance needed. Stale air sets off personal mental alarm systems rather effectively.

But we must also treat waste water, both gray (sink, shower) and black (toilet wastes: urine and feces) locally. Not only does this give us a further opportunity to "grow fresh air" within ever module that has a toilet system, but it helps pretreat blackwater at the source of the problem, greatly reducing the treatment burden to be handled in a centralized, or, better (in tune with our "as the settlement grows" philosophy), in neighborhood facilities. Wastewater treatment systems that "grow clean water" should be in every habitation and activity module: not just in residential quarters, but wherever people work, shop, go to school, play, or are entertained.

Many systems have been tried, some of them quite ingenious, mostly in rural settings that lack central water treatment systems. Some of these systems require an exhaust to the exterior atmosphere sink to handle the odor problem. As we can't exhaust stinky air outside on the Moon, at least not routinely, many "composting" toilet systems that work perfectly well on Earth will not pass muster on the Moon. The odor problem must be handled on the inside! That creates an extra burden, which to any one with the proper attitude, translates to an inviting "challenge," the kind of incentive that spurs ingenuity to greater achievement.

The Wolverton gray water system is one option that has worked for nearly 30 years in the home of retired NASA environmental engineer, Bill Wolverton in Houston.



KEY: 1 side- or wall-flush toilet; **2** blackwater tank with microbes to break down solids & destroy pathogens; **3** inert filter with irrigated soil; **4** plants rooted in wet soil mixture; **5** effluent water is 95% pretreated, ready to water plants In the greenhouse and elsewhere. – illustration by the author.

There are undoubtedly other systems systems, but Dr. Wolverton’s well-tested system sets the bar against which other systems must be measured. The system above handles the load imposed by two people. We need to know to how many people-hours per day that translates. Are they home all day, everyday? Or half the day most days? Blackwater systems must be rated in people-hours capacity if we are to size them to the daily loads of other activity modules such as work spaces, offices, schools, shopping areas, etc.

If we can someday deploy a modular lunar analog research station facility, we will want to try a variety of such systems in order to verify how well they work, and how they compare on various performance parameters. This fits the goal of such an analog facility to demonstrate the technologies needed for actively growing lunar outposts and settlements. There may well be a commercial component of such experimentation, with various manufacturers contributing systems for the various modules in a high-stakes game of make or break.

The penalty of not aggressively developing a full suite of modular biospheric technologies is clear. The planned “visitable” (but no longer intended to be permanently manned) outpost must be constantly resupplied from Earth, or by a very wasteful program of local throwaway oxygen and water production. Engineers and architects of modules may prefer to “keep it clean, and sterile” but our job is to create a “biosphere flywheel” that largely maintains itself with a modest amount of monitoring. We need to keep dependence on resupply from Earth to a minimum, if we are going to progress to the point where those on the Moon can survive politically or economically driven cutoffs of support, be they temporary or indefinite. This must be our goal! <**MMM**>

MMM # 207 - AUG 2007

M O D U L A R

B I O S P H E R I C S

V*. “Tritreme Drain Plumbing” - By separating drainage by source type, each can be more efficiently treated.

By Peter Kokh

[Treme (Greek) = hole] Cf. MMM #40 NOV ‘90, “**Cloacal vs. Tritreme Plumbing**” [reprinted in MMM Classic #4, pp. 65-66]

Except in "new towns", it would be prohibitively expensive to switch to a new 'multi-treme' system, which keeps different types of sewerage separate from the beginning in order to benefit from simpler and more efficient source-appropriate forms of treatment, with the fringe benefit of enjoying whatever valuable byproducts such separate treatment may promise. Lunar and space settlements are "new towns". Infrastructure is 'change-resistant'. Thus it is of supreme importance to choose it wisely from day one.

Purging ourselves of the MIFSLA habit

The “MIx-First-Separate-LAter” (MIFSLA)* attitude to waste water management” has gone virtually unques-tioned since the invention of urban sewage systems in a city whose name we do not know, but whose ruins we refer to as Mohenjo-Daro, on the Indus River, about 200 miles NNE of modern Karachi, Pakistan, in 2,500 BC, four and a half thousand years ago. Another case of infra-structure being the most difficult thing to change, and thus the thing that deserves the most attention.

MIFSLA is so ingrained, it is taken for granted, almost never questioned, never thought of. “It’s just the way we have always done it.” How many times have you heard someone say that about something?

Waste Water treatment by Source Separation

www.holon.se/folke/projects/vatpark/Kth/guntha.shtml

On the Moon, where we are starting fresh, we have not only the ideal opportunity to do so, but an urgent imperative. Creating and maintaining a functional biosphere is daunting enough. Creating one that will keep operating as both the settlement and its biosphere keep growing ever larger.

> “The conventional waste water management system is unable to purify the sewage water to a higher grade than the nutrient content of the grey water. Biological plants are not well adapted to the purification of a mixed sewage, but if source separating toilets are used, the urine and feces could be used for agriculture, and the grey water could be efficiently purified with biological methods to a grade that it can be reused in the settlement.” Folke Günther, Stockholm – URL above

Obviously, if we are going to build and grow settlement biospheres in modular fashion, with contributing components in each new habitation and activity module, we don’t need to make it more difficulty simply for the sake of “the easiest (most familiar) way.”

The MIFSLA Way of Doing (or not doing) **Business**

- Clean water is mixed with urine and feces to a polluting mixture, both regarding plant nutrients and pathogens.
- This mixture is in turn mixed with a fairly clean grey water (sinks, bathtubs, showers, laundry).
- The resulting mixture is diluted with drainage water (rain) (About 80 m3/person*year [19]) in an extensive web of piping.
- Finally, the mixture is expensively purified to a quality comparable with the original grey water, but with a doubled volume.

Folke Günther, Stockholm – URL above

Wetlands-type systems accepting MIFSLA loads do not do as good a job, especially in reducing phosphorus content, as would be possible if the differing loads were treated separately.

Common Toilets mix wastes also

In the common water closet, urine and feces are water-flushed together. But there are several designs which separate most of the urine from the feces, so that both can be treated and recycled as agricultural fertilizers separately. There are several types of composting toilets designed for off-the-plumbing-grid use, and they function well, if instructions are followed.

At the Mars Desert Research Station, the original toilet was a composting one, operated poorly, with high odor problems. This may have been the result of improper installation, but more likely was the result of higher load (more users) than it was designed for.

We personally favor the Wolverton System, in which combined urine and feces are flushed into a tank inoculated with microbes to destroy the pathogens and break down solids, the effluent feeding a runoff planters producing clean fresh odor-free air, green foliage, under sunlit conditions. Such systems are load-restricted, but if used in every habitation or activity module in a number to match expected loads, would both turn the black water into gray water while contributing to the biosphere mass and function. This seems the best match for “Modular Biospherics” that we have seen, however, improvements and alternatives are always welcome.

In our earlier article, written long before we heard of the Wolverton system, we suggested that toilet wastes be collected in changeable holding tanks. You would put a full one “out front” to be replaced with an empty one, by a municipal utility service. Utility personnel could make the switch in your home at an extra fee for convenience.

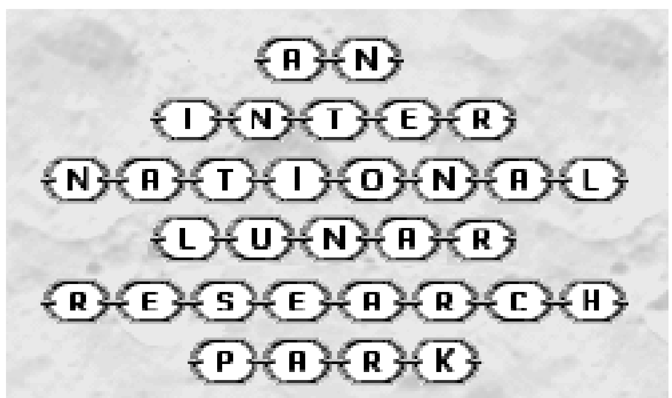
Separate drainage can be carried much further. Waste water from various types of industrial operations each have varying types of adulteration, each suitable for a special kind of treatment. Mixing industrial waste waters makes no sense and compounds the problems.

To insure proper installation and connections, drainage systems meant for different types of effluent could be color-coded. This is a system that we can make work. We need only the will to do it right.

Separate Gray Water Benefit

Pretreated odor-free gray waters irrigate “Living Walls” and can feed waterfalls, fish streams, fountains, and other delightful water features. The result would be a more pleasant settlement. **<MMM>**

MMM # 224 - APR 2009



AN INTERNATIONAL LUNAR RESEARCH PARK

An Open-ended Lunar Initiative v. 2*

By Peter Kokh and David Dietzler

• V.1 published in MMM-India Quarterly (Feb. 2009)

Current Prospects

The United States, under former President George W. Bush, redirected its ISS and Planetary Exploration-focused Space Program to a “return to the Moon” and “beyond to Mars.” This direction will probably continue under President Barack Obama. Meanwhile, China, India, and Japan have launched lunar probes and spoken of putting crews on the Moon. Whether these will be one time “science picnics” å la Apollo or real efforts to establish permanent facilities to support manned exploration sorties and other activities remain to be seen.

The Question

If each nation picks a different location on the Moon for its surface activities, areas of cooperation are limited to data sharing, tracking, and other support activities.

If, however, some or all national lunar outpost efforts are concentrated at one and the same location, be it at the north or south lunar poles or somewhere else, then the opportunities for shared facilities is enormously increased, and with it could come major savings by reducing unnecessary duplications.

Shared Facilities: Corporate Partners

Of course, then the question becomes "who will build and provide the facilities to be shared? And right here we have the opportunity to introduce new parties: contractor companies. Possible contractors could include Boeing, Lockheed-Martin, EADS, Antrim, and other names associated with the Aerospace industry, but also other major contractors. To pick a few: Bechtel, Halliburton, Mitsubishi, and on and on.

Added Players: Enterprise, University Consortia

If we collectively choose to establish not a collection of national outposts, collocated or not, but an "**International Lunar Research Park**" the possibilities for future expansion, elaboration, and outgrowth – even into the 1st human lunar settlement – will increase greatly.

Facility Lists

The lists below are meant to show how great are he possibilities for diversification and outgrowth. The items in **bold** will come first. Plain type next, italics last. Note, that this sub-classification is just one person's first attempt, and corrective input is most welcome. No one expects to "get it right" the first time! What we want to do is to put out the general concept of how enormously the choice of an International Lunar Research Park could bust the future wide open. After the itemized lists (we surely have forgotten or not thought of many items!) we will give our thoughts on just what must come first.

National Outpost "Core" Elements

- Base habitat
- Base laboratories
- Basic life support
- Command center
- Airlock

Contractor Corporation Services

- Site preparation
- Spaceport services
- Construction equipment
- Shielding services
- Solar wind gas scavenging
- Fuel storage
- Fuel production
- Power generation
- Power storage
- Warehousing systems
- Thermal management
- Waste treatment
- ISRU Research
- ISRU Manufacturing
- Habitat expansion modules
- Agricultural modules, basic agricultural services
- Biosphere maintenance
- Road construction
- Connector modules

Enterprise Opportunities

- Commons with meeting space

- Restaurant(s), pub(s)
- Recreational facilities: exercise, sports, dance, theater
- TV/Radio Facilities, satellite communications
- Telephone system, internet provider
- Instruction, continuing education – keeping up to date with improved lunar systems
- Financial services
- Hotel facilities for visitors, tourists, overflow between crew changes
- Cabbotage (outfitting) services
- Surface transportation (passenger, freight)
- Vehicle maintenance
- Space suit services
- Tools, equipment
- Recycling services
- Tour coaches & excursion services
- Marketplace
- Agricultural production, products
- Green (horticultural) services
- Reassignment services (new roles for scavenged parts of landers etc.)
- Agricultural production
- Customization services
- Event management
- Surface recreation vehicles
- Archiving services

University Consortia

- Medical Center
- Continuing education
- Research facilities
- Astronomy installations

Joint Civic

- Road planning local
- Road planning regional
- Environment protection
- Environment enhancement
- Inter-Sector coordination (Contractors, Enterprise, National, University)
- Parks, parkways, gardens
- Outstation planning

Discussion – where you come in!

It would be miraculous if the list above did not have many holes, even if nothing was misclassified. Your input is most welcome!

The effort above is an attempt to start a discussion and to keep us, nationals of the various countries contemplating lunar surface activities, from being blindsighted to the enormous advantages to be gained not only by collaboration between the various national agencies, but by restraining agency hubris and by taking the plunge to invite corporate, enterprise, and university consortia as equal partners in a joint "human" effort.

The idea is for the national outpost agencies to buy or lease or tent equipment and services from the contractors and enterprises as their needs change and expand. This should provide not only substantial cost savings but a greater variety and supply of equipment and services.

Agencies need not provide quality and other specifications, because corporate and enterprise personnel would be just as much as risk from improperly designed and manufactured equipment as would national agency crews. Toss out the mind-boggling bureaucratic paperwork, and down comes the costs.

Corporation employees would need housing, and all the other life support services as needed by the agency crews so it is natural, that as they begin to construct pressurized modules and other equipment from lunar building materials that they could provide for expansion of national outposts as well at considerable savings.

The national outposts would be “anchor tenants” so to speak, but as in shopping malls, in time their share of the economic value of total activities and facilities at the site might become, even though essential.

Some sort of Civic Council representing all of these Parties would be needed to make decisions that affect every-one, decisions about growth directions, environmental safeguards, and so on. As this unfolds, the International Lunar Research Park will have become the first lunar settlement!

It is time for humanity to open the next continent, one across a different kind of sea. The “out of Africa” effort is ready for the next act. Only humans as a species, not horse-blindered agency managers, have the vision to grasp what is needed - and it is not a collection of agency outposts!

What Comes First?

Frankly, national agency planning puts the cart before the horse. Why? Two things come first, and no one is giving either of them more than trivial attention.

Part I: Developing now the Technologies needed for using lunar resources

We are not going to anything of lasting significance on the Moon unless we learn how to process useful building materials out of the elements in moondust. Known by the uppity Latin term “In Situ” Resource Utilization (“on location” works just fine!) various processes have been proposed to isolate oxygen and other elements, but few have been tested either in laboratory scale or (more importantly) in mass production scale. How do we advance the “readiness” state” of these technologies? It is important to have them ready to go when we land on the Moon. Getting there, and then having to scratch our heads for additional time-wasting decades makes no sense. But that is the path we are on.

This topic is the subject of **“Improving the Moon Starts on Earth”** in MMM #s 132,133, Feb/Mar 2000.

Part 2 - Site Development

No site on the Moon, no matter what advantages are touted on its behalf, is anything but “unimproved” land, what in might be called “Florida swampland.”

Before the first national agency manned lander sets down on a chosen site, it makes sense for a corporate contractor to have already “improved the site” - conferring on it various advantages that will make outpost deployment, construction, and operation so much easier. Indeed, Carnegie-Mellon University, a contestant for the Google Lunar X-Prize, has just proposed that establishment of the first spaceport be contracted to the university to be done by telerobotics.

www.post-gazette.com/pg/09063/952880-115.stm

This is the subject of the article, **“The Developer’s Role”** from Moon Miners’ Manifesto #131, December 1999.

Both articles are combined in one Online Paper:

“Improving the Moon & the Developers Role”

www.lunar-reclamation.org/papers/improving_moon_paper.htm

Also relevant, “The Outpost Trap” serialized in MMM #s, 198, 199, 200 September, October, November 2006

www.lunar-reclamation.org/papers/outpost_trap.html

<PK/DD>

Lunar Research & Development Priorities List: 1-5

By David Dietzler - pioneer137@yahoo.com

1a) Space Transportation: cheap access to space - CATS, from inexpensive expendable and/or reusable Earth to LEO launchers to ion drive or sail propelled craft for transport from LEO to LLO, L1, etc.

1b) Lunar derived fuels / propellants for lunar landers after some initial development on the Moon. Ion drives and sails are only good for cargos, not manned craft, given the great length of time they require for travel to LLO and therefore exposure to Van Allen Belt radiation, as well as life support. Thus we also need orbital fuel depot infrastructure. The cost barrier must be broken.

2A) Life Support Systems for prolonged (months, even years) human stays in space

2B) AI robotics for the majority of work done in space

3) **Production of oxygen**, other gases, metals and ceramics from lunar materials (some of this is included in category 1, for the production of rocket propellants on the Moon, given the assumption that lunar derived fuels will be cheaper than boosting them from Earth to LEO, although this assumption might be challenged depending on how much infrastructure on the Moon and in space would be needed, when it would be needed, how low the cost of launching to LEO goes, and how many manned flights would be called for given that robot power not manpower will do most of the work

Lots of research has been done on Oxygen production and most of it has been done with simulants only on laboratory bench top scales for short periods of time. Much more research must be done with real regolith using equipment that is built to work in vacuum, low G, hard radiation and temperature extremes for extended periods of time-years, not just weeks or months. Understanding the chemistry of regolith refining is just square one. A vast amount of R&D is required to build the equipment that does the work from shovel to final product and to determine which processes will scale up from the lab bench to the industrial level, work reliably for years in the lunar environment, demonstrate the greatest economy in terms of labor, time and energy required; require the least amount of input from Earth (some processes will require chemicals from Earth that must be carefully recycled) and the most amount of "Moon-makability." We will need to replicate this equipment on the Moon from lunar materials to expand production rather than constantly import devices from Earth hence the need for "Moon-makability" otherwise the cost of ISRU will be too high.|

Prerequisite to production of lunar materials is energy production. It's going to take a lot of energy to smelt or refine regolith so we will have to land substantial payloads of reflectors, concentrating lenses or mirrors, solar panels, batteries and/or fuel cells and fuel cell reactant storage equipment, cables, switches, inverters and possibly small nuclear reactors. We will need to expand energy production as materials production grows and this takes us to the next category:

4) Lunar manufacturing: what to make and how to make it as well as what to make it from. Once we get past the hurdle of producing gases, metals and ceramics on the Moon we have to figure out how to make more devices for producing them from the gases, metals and ceramics available on the Moon. It won't be much use if the regolith refining devices require large amounts of gold, copper, zinc, fluorine or other elements from Earth. We cannot upport huge masses of equipment, even with what passes for "cheap access to space" in the future, because even CATS will still be expensive compared to transportation on Earth. We must upport a seed of regolith refining and manufacturing devices that can replicate itself in order to refine more regolith and produce more materials as well as make things from those materials like solar panels, power storage systems, habitat, farm modules, robots, vehicles, machine tools and mass drivers for launching millions of tons of lunar materials into space for SPS construction.

To grow the mighty tree of space industry on the grand scale envisioned ever since O'Neill wrote "The High Frontier" from a tiny seed amassing perhaps just hundreds of tons will require a lot of brainpower, real world experience, and some sophisticated AI robot software as well as hardware. At this time even the experts can only take shots in the dark as to what that seed will consist of. It's fun to speculate about the payloads this seed might consist of, but only after some extensive R&D on the ground and on the Moon during NASA's RTM program and some high paid teams of mission planners have had years to work on this will we know exactly what the lunar industrial seed will consist of. Because of the high price of even CATS in the future it will be essential to minimize the mass of the lunar Industrial seed machines, maximize the use of local materials, and maximize the lifetime, durability and efficiency of the seed. Also, the seed must be reasonably priced. What good will it be to use a one-ton machine that costs a billion dollars if a ten ton machine can do that job and be transported to the Moon for much less than a billion dollars? In other words, when does miniturization start costing more than rocket transport?

As for nanomachines, I have no doubt that nano-technology will be involved in lunar industrialization but I don't go as far as suggesting that a few kilograms of nanobots will replicate like a growing algae bloom and lunar colonies will emerge from that. I do not have anything against that scenario, I just don't buy it. I would love to be wrong but I suspect that lunar industrial seed will amass several hundred to several thousand tons and even that will be tiny compared to the millions of tons of lunar industry and SPSs that emerge from that over time.

5) Space construction. We have never built anything as large as a solar power satellite in outer space. What will it take to do this? We can presume that lunar aluminum, silicon and titanium, possibly some steel and glass, will be used but how will billets of metal from the Moon be turned into SPSs? What machines will be needed? How do we get those machines in space? Launch them from Earth or make them on the Moon and launch them from the Moon or will a combination of Earth launched and Moon made/Moon launched machines be used? Will we need a space colony and 10,000 space workers or will we just station a small human crew in space and use thousands of robots teleoperated by humans on Earth and on the Moon?

MMM #232 - FEB 2010

Lunar Base Preconstruction

A Basic Public Demonstration of Using Moondust to Make Building Materials

By Peter Kokh

PK: I had been invited to sit in on a presentation of Jay Witner's "Apollo Village Proposal" during the 2009 Inter-national Space Development Conference in Orlando, FL over the Memorial Day Weekend.

To put it in a nutshell, Jay was proposing that we raise seed money approaching one million dollars to convince the government to fund a pre-construction mission on the Moon. Teleoperated bulldozers and other equipment would be sent to a spot on the Moon that had been previously selected for a NASA Moonbase. At that location, the selected equipment would be delivered by a Delta launcher and begin to "make bricks."

Jay would use solar concentrators to melt moon dust in molds. Actually, you can compact moon dust and use microwaves to sinter and stabilize the outer layers, and for many purposes that would be good enough.

"The public has never been shown that we can go to space and build structures out of local materials. Live video of buildings going up on the face of the Moon is an incredibly powerful means to ignite interest in and support of our space program."

We do not have the expertise to weigh the merits of Witner's proposed methods. Nor should this article be construed as an acceptance of their feasibility. But his proposal did get us to thinking:

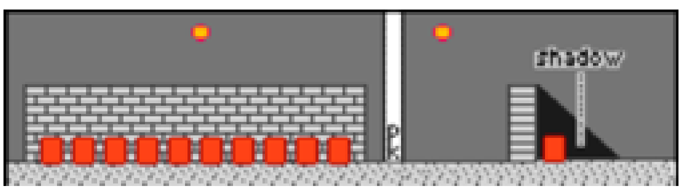
What can we do with bricks made by sintering?

The suggestion that we make buildings ready for astronauts to occupy seems to us to be rather imprac-tical. It is our own non-professional expectation that no structure made of bricks, no matter how well made, can hold pressure against the outside vacuum.

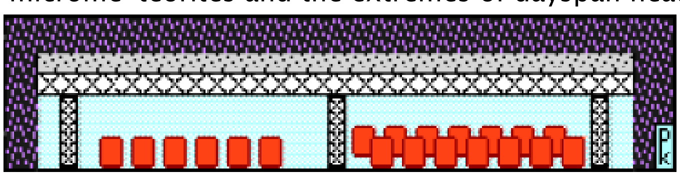
But fortunately that does not exhaust the possi-bilities. There are sevreral practical construction projects in which brick structures can play a supporting role in setting up a lunar outpost. Let's look at some of them.

Depending on the north/south latitude of your chosen location on the Moon, brick walls could provide shade for things stored out on the surface that must be kept cool, or at least, must not be allowed to get too hot; Tanks of fuel and/or various gasses, for example. Tanks storing blackwater (toilet) wastes are another example. Eventually, such wastes will prove most valuable as a source of agricultural nutrients, but we may not be ready for such operations right off the bat.

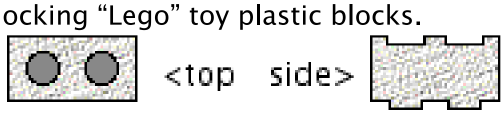
How high a shade wall would have to be will depend on the latitude. At the equator, it would throw no shadow and be useless. Such walls will be more helpful at middle to polar latitudes.



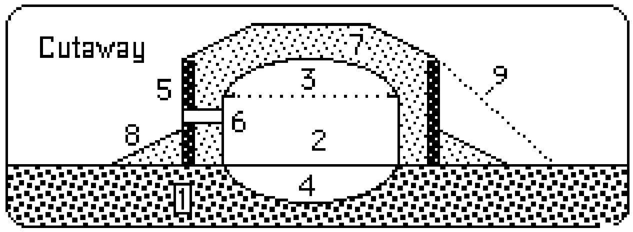
Bricks can also be assembled into columns sturdy enough to support space-frame canopies for unpressurized lee-vacuum storage areas protected from the cosmic elements of radiation, solar flares, microme-teorites and the extremes of dayspan heat.



As we are talking about mortarless applications, a better brick/block design would take a cue from the familiar interlocking "Lego" toy plastic blocks.

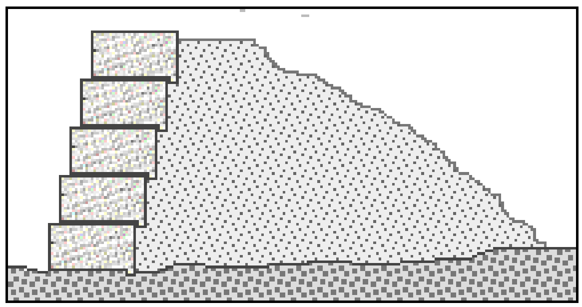


Another use for simple bricks would be to create retaining walls for moodust used as shielding.



In the illustration above, (9) represents the slope of the moondust shielding mound if a retaining wall were not used. Now in 1/6th gravity, the weight of the retained moondust might not exert enough pressure to topple a well-built brick wall. Experience will tell, however.

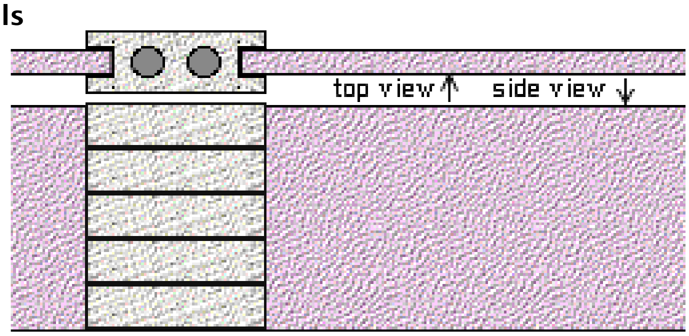
A better option would be to use the bottom lip design of retaining wall landscaping blocks



Beyond bricks: pavers

Closely related to bricks are "pavers" which can be brick like in size and thickness up to much bigger slabs. These would have a use as well, for example serving as pavement for rocket landing/launch pads to cut down on the spray of sandblasting moondust driven by rocket exhaust. Such pads would be bermed as well to present a horizontal barrier; and these berms could well be confined between retaining walls.

Beyond bricks: panels

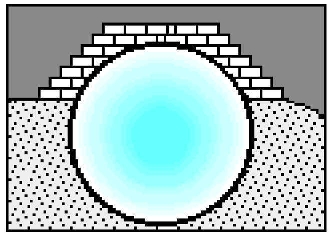


Panels, whether of concrete or made in the same moondust sintering fashion as bricks and blocks, could be held in place by Lego type blocks with forked ends.

Such panel walls could be used to shade stored items that need to be kept within specific temperature ranges, as mentioned above. They can also be used as visual barriers along roads and paths, blocking the view of warehousing and recycling sites, for example.

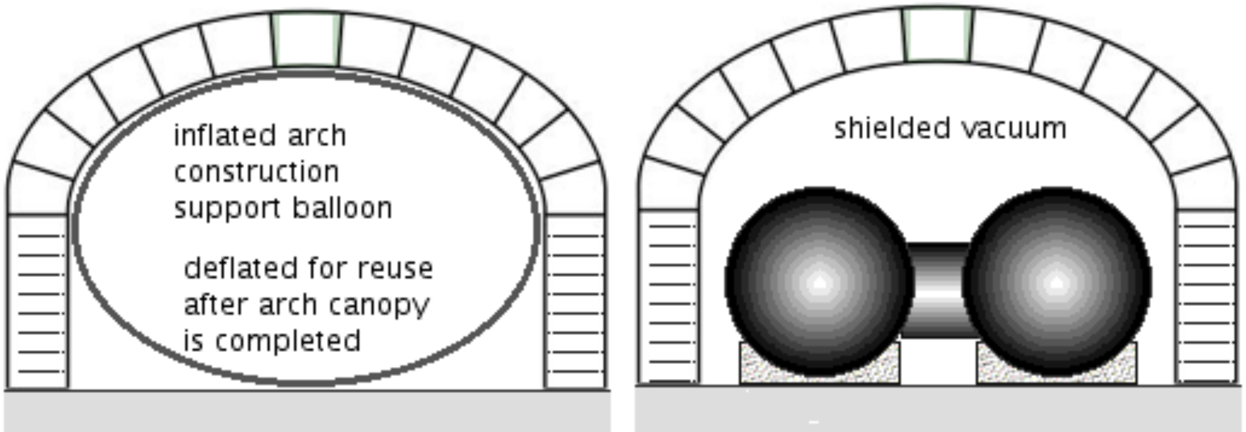
From Romance to the Prosaic

We must be brutally honest and say that we see no construction role for bricks in creating lunar shelter other than as retaining walls for moondust shielding



However, this form of shielding can only be constructed after the habitat module is in place.

However, there is one way to create a brick/block shelter before any pressurized modules arrive from Earth. That would be to use blocks designed for arches. You could build interlocking rows of arches over a temporary supporting inflatable structure.



Should the Apollo Village proposal of presenting NASA with ready-made shelters is unrealistic, we can help to prepare a site for NASA by creating a supply of bricks/blocks which could come in handy in many ways.

What about sandbags?

As implied, we could also create piles of ready-to-use sandbags. It would boost the viability of this option, however, if we could make the “bag” from local material: glass or basalt fiber mesh. But a lot of prior experimentation will be needed to demonstrate that this can be done early on, on the Moon.

What about pressurized buildings?

Except for the unpressurized arched canopy option, even if we can’t put up brick buildings, ready for NASA or anyone other agency to use, it is clear that we can provide brick, block, paver, and panel structures that will go a long way to making the job of setting up shop on the Moon that much easier. And this would go a long way towards serving the same purposes as The Apollo Village Proposal has been designed to do.

Who gets to teleoperate the brick making, and deployment controls?

Such a project, coordinated with NASA or any other contracting tenant, would be an early indication that a base was about to become real. Indeed, we think that we can make this proposal even more interesting by expanding on the teleoperation angle. Finding ways to select individuals from the public at large by lottery of other means and give them a turn behind the brick/block manufacture and deployment teleoperation controls, would give this project significant public attention.

We’d have to train lottery winners, and they would only get a chance to do actual work on the Moon remotely, if they demonstrated a required level of expertise. But to win and then be approved for this privilege would and then actually get to do some of the work on the Moon would be a lifetime feat hard to surpass, surely something to tell the grandchildren about.

While waiting for NASA, we can do more!

The Apollo Village Proposal suggests that space enthusiasts raise a million dollars or so for a publicity campaign that would get NASA to put in the budget the money needed to deliver the required equipment to the Moon. I think that misses major opportunities.

Why wait for NASA to do the brick and block design, to develop the equipment needed and which is to be teleoperated? Can't we help do that? NASA now has college and university groups help ferret our design options by such means as Rover competitions, regolith-moving competitions, and so on. It would seem that the next step, is not to raise money for a publicity campaign, but to get NASA to sponsor a new set of Engineering Challenges. This would involve many young people across the country in brainstorming how, indeed, we could do something like this: manufacture bricks, blocks, pavers, panels etc. on the Moon, ready for NASA or whomever to use. The moondust handling equipment as well as the manufacturing equipment needs to be pre-engineered and tested.

This would include tests using regolith moon dust simulant to see what process would work best and require the least weight of equipment and the least energy to produce the bricks and blocks. The proposal suggests using solar concentrators to melt moondust in molds. But sintering moondust compacted in molds by using microwaves could work if the product performance is sufficient.

While we could expect college and university teams to be eager to get involved, NSS chapters and chapters of other space organizations should be allowed to try their talents. What more captivating an activity could one imagine for chapter public outreach? Of course, most chapters would be hard pressed to put together a team with sufficient talents, and to purchase necessary supplies and equipment. But let's give them the chance!

A dedicated website for this project would showcase:

- √ Product design and service purpose options
- √ Equipment design and performance
- √ Progress along related lines such as design of sandbags, which could be made on site of lunar materials, and automated/teleoperated sandbagging equipment
- √ Illustrations and artwork
- √ Photo gallery
- √ List of college/university teams involved
- √ List of other teams (chapter-based, etc.)
- √ Information about related NASA Challenge events
- √ Updates on Moonbase plans of various agencies

The Moon Society could host such a site, but the National Space Society could do so also. Meanwhile, progress could be show-cased at the annual International Space Development Conferences, and any demonstrations would be sure to attract a crowd. This activity could be a welcome added draw for the ISDC.

Can we push this idea further?

We do not now know where the first moon base will be located, or at least a few of us not on the band-wagon do not know. The South Pole location is very hilly and rugged and a builder's challenge. A site on or near a mare/highland coast would allow us to similarly pre-manufacture cast and/or hewn basalt products (from tiles to blocks) as well. A site which had flat areas for an initial base to morph into an industrial settlement, as well as nearby high ground for overlooks as well as scenic relief, would be visually more interesting.

Imagine that we find such a place, and prior to first base module landing, prepare the site not just by grading it and building a launch pad, but by tele-manufacturing bricks, blocks, pavers, panels, etc. for multiple helpful uses. Then, while waiting for the base components themselves to arrive, we tele-construct a "nature trail" to and up on any overlooking high ground. Our bricks, blocks, pavers, and panels could be used to make steps, restraining walls too near any precipices, benches to rest on along the way, and a paved, walled overlook on top with the panorama of the ever growing base-into-settlement below.

If such a trail were tele-constructed before the first crews arrived, it would be a welcome after-work and free time diversion to check on the progress from an overlook like this. What could we do to make the first crews feel more welcome than to have such a “Jay Witner” trail ready for them?

In summary, even if the Apollo Village Proposal should prove to go too far, we think that that the general idea of providing pre-construction building materials out of moon dust by teleoperation has great potential, both to speed up construction of an operational Moonbase and to excite the public beforehand.

And we thank Jay Witner for that! **PK**

MMM #234 - APR 2010

LUNAR BASALT

What, Where, and its Critical Role for Lunar Industrialization and Settlement Construction

By David Dietzler with contributions from Peter Kokh

1) Technical Terms and Chemical Description of “Basalt,” “Gabbo,” “Lava,” “Magma”

Basalt is hardened surface “lava. Hardened subsurface lava is called gabbro. Molten surface rock is called lava and molten subsurface rock is called magma.

The lunar mare areas are covered with basalt pulverized into a fine powder by eons of meteoric bombardment. This material will be relatively easy to mine with power shovels.

This regolith consists of pyroxenes (iron, magne-sium, and calcium silicates: SiO_3), olivines (iron and magnesium silicates Si_2O_4), ilmenite $FeTiO_3$, spinels and plagioclase $CaAl_2Si_2O_8$.

Lunar basalts are classified as high, low and very-low titanium basalts depending on ilmenite and Ti bearing spinel content. **They differ from their terres-trial counterparts** principally in their high iron contents, which range from about 17 to 22 wt% FeO. They also exhibit a range of titanium concentrations from less than 1 wt% TiO_2 to 13 wt% TiO_2. A continuum of Ti concentra-tions exists with the highest Ti concentrations being least abundant. Lunar basalts differ from terrestrial basalts in that they show lots of shock metamorphism, are not as oxidized and lack hydration completely.

See: **http://en.wikipedia.org/wiki/Basalt**

Olivine contents range from 0% to 20%. Basalts from the mare edges or coasts probably contain more plagioclase, the mineral that makes up most of highland soils, than basalts closer to the center of the mare.

Types of Processed Basalt

- **Cast Basalt:** Basalt can be melted in solar furnaces, cast into many forms, and heated again and allowed to cool slowly (annealing) to recrystallize and strengthen the cast items. It can be cast in iron molds and possibly in simple sand molds dug into the surface of the Moon.

Iron could be obtained by harvesting meteoric Fe-Ni fines that compose up to 0.5% of the regolith with rovers equipped with magnetic extractors. Iron molds could be cast in high alumina cement molds. The high alumina cement could be obtained by roasting highland regolith in furnaces at 1800-2000 K to drive off silica and enrich CaO content. This could be hydrated in inflatable chambers with condensors to recover water vapor. It might also be cost effective to upport iron molds to the Moon since they would have a very long lifetime.

- **Sintered basalt** is not fully melted. It is placed in molds, pressed, and heated with microwaves or solar heat just long enough for the edges of the particles to fuse. This will require less energy than casting. Sintered Basalt can be used for low-performance external building blocks, pavers, and other uses.

- **Drawn basalt fibers** are made by melting basalt and extruding it through platinum bushings.
- **Hewn basalt** quarried from bedrock, road cuts, or lava tube walls. Can be cut with diamond wire saws.

2) Uses of Basalt: source:
http://en.wikisource.org/wiki/Advanced_Automation_for_Space_Missions/Chapter_4.2.2
Table 4.16 Lunar Factory Applications of Processed Basalt

Cast Basalt - Industrial uses

• Machine base supports (lathes, milling machines)
• Furnace lining for resources extraction operations
• Large tool beds • Crusher jaws • Sidings
• Expendable ablative hull material (possibly composited with spun basalt)
• Track rails reinforced with iron prestressed in tension
• Railroad ties using prestressed internal rods made from iron
• Pylons reinforced with iron mesh and bars • Supports and backing for solar collectors
• Heavy duty containers (planters) for "agricultural" use
• Radar dish or mirror frames• Thermal rods or heat pipes housings
• Cold forming of Metal fabrication with heat shrink outer shell rolling surfaces

[Current industrial uses omitted above]

• Abrasion-resistant Pipes and conduits • Abrasion-resistant floor tiles and bricks
• Abrasion-resistant Conveyor material (pneumatic, hydraulic, sliding)
• Abrasion-resistant Linings for ball, tube or pug mills, flue ducts, ventilators, cyclers, drains, mixers, tanks, electrolyzers, and mineral dressing equipment

Cast Basalt - commercial, agricultural, & residential uses (omitted on source list above)

• large diameter (3" plus) pipe for water mains and for toilet and sewer drainage systems
• floor tiles • countertops, tabletops, backsplashes • planters and tubs of all sizes, flower pots
• possibly contoured seating surfaces (contoured seats lessen the need for resilient padding, cushions)
• lamp bases • many other commercial and domestic uses

Sintered Basalt (from URL reference above)

• Nozzles • Tubing • Wire-drawing dies • Ball bearings • Wheels • Studs
• Low torque fasteners • Furniture and utensils • Low load axles • Light tools
• Scientific equipment, frames and yokes • Light duty containers and flasks for laboratory use
• Pump housings • Filters/partial plugs

{Logical lunar uses omitted from above list]

• Blocks for shielding retainer walls • Slabs for airlock approaches, external paths and walks
• lightweight light-duty crates and boxes • Acoustic insulation • Thermal insulation
• Insulator for prevention of cold welding of metals • Filler in sintered "soil" cement
• Packing material • Electrical insulation
• "Case goods" furniture as we might use wood composites such as OSB, MDF, etc.

Basalt Fiber - Uses (in place of glass fibers)

• Cloth and bedding, pads and matts • Resilient shock absorbing pads • Acoustic insulation
• Thermal insulation • Insulator for prevention of cold welding of metals • Fine springs
• Filler in sintered "soil" cement • Packing material • Electrical insulation
• Strainers or filters for industrial or agricultural use • Ropes for cables (with coatings)

[In Gujarat at M .S. Univ., Kalabhavan, Baroda, basalt fibers are used as a reinforcing material for fabrics, having better physicomechanical properties than fiberglass, but significantly

cheaper than carbon fiber.] www.fibre2fashion.com/industry-article/3/256/new-reinforced-material1.asp
• brake pads? http://www.technobasalt.com/news/?id=14 http://www.basalt-tech.ru/en/prospects
Hewn Basalt (MMM's list)
• Heavy duty Building blocks • Road paving slabs • Heavy duty floor slabs
• Architectural pillars, headers, arches ª Carving blocks for sculpture statues, other artifacts
• lamp bases, mancala/oware boards, etc. • fountains, bowls, table pedestals, vases, etc.
• statues, plaques, beads, bracelets, endless list

3) Properties of basalt From-- http://www.islandone.org/MMSG/aasm/AASM5C.html

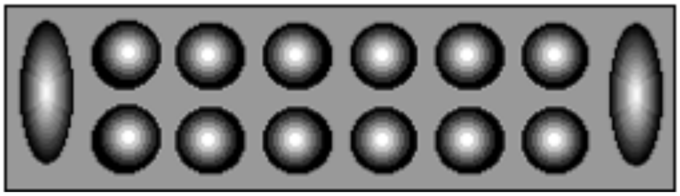
Table 5.9.- Properties Of Cast Basalt

Physical properties Average numerical value, MKS units
Density of magma @ 1473 K 2600-2700 kg/m3 Density of solid 2900-2960 kg/m3
Hygroscopicity 0.1% Tensile strength 3.5X107 N/m2 Compressive strength 5.4X108 N/m2
Bending strength 4.5X107 N/m2 Modulus of elasticity (Young's modulus) 1.1X1011 N/m2
Moh's hardness 8.5 Grinding hardness 2.2X105 m2/m3
Specific heat 840 J/kg K Melting point 1400-1600 K Heat of fusion 4.2X105 J/kg (+/-30%)
Thermal conductivity 0.8 W/m K
Linear thermal expansion coefficient ... 273-373 K 7.7X10-6 m/m K ... 273-473 K 8.6X10-6 m/m K
Thermal shock resistance 150 K Surface resistivity 1.0X1010 ohm-m
Internal resistivity 1.0X109 ohm-m Basalt magma viscosity 102-105 N-sec/m2
Magma surface tension 0.27-0.35 N/m
Velocity of sound, in melt @ 1500 K 2300 m/sec (compression wave)
Velocity of sound, solid @ 1000 K 5700 m/sec (compression wave)
Resistivity of melt @ 1500 K 1.0X10-4 ohm-m (author's note--this is of importance to magma electrolysis which requires an electrically conductive melt)
Thermal conductivity, ... melt @ 1500 K 0.4-1.3 W/m K... solid @ STP 1.7-2.5 W/m K
Magnetic susceptibility 0.1-4.0X10-8 V/kg
Crystal growth rate 0.02-6X10-9 m/sec Shear strength ~108 N/m2

4) **Gallery of Basalt Products**


L: Cast Basalt Pipes R: Hewn & Carved Basalt

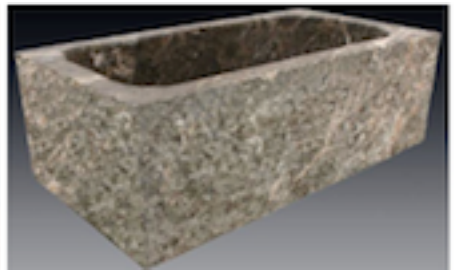
With unequalled abrasion-resistance, such pipes and chutes will be prerequisite for all moon dust handling industries, even for oxygen production.



A Mancala or Oware game board

Cast Basalt tiles (Czech Republic)

Cast basalt planter



A Bathtub

Note: The above are individually crafted items. Production items include pipes and tiles of various kinds.

Basalt: What Does All This Mean?

By Peter Kokh and Dave Dietzler

The cute things such as what you can carve out of solid basalt, aside, the essential message is in the abrasion resistance of basalt vs. the very abrasive nature of moon dust out of which we are going to have to make as much as possible. The name of the game is to produce locally on the Moon as much as possible of local frontier needs, and to develop export markets for those things, to defray imports on the one hand, and to earn credits to import what they cannot produce on the other hand.

Our Thesis: A lunar basalt industry is **pre-requisite** to any other lunar materials industry. Unless we prefer to bring from Earth, all items needed to handle abrasive material such as moon dust,

Lunar industrial settlement must have access to basalt

We believe that we must start in the maria, preferably along a mare/highland coast with access to both major suites of lunar material. The Lunar North Pole is some 600 miles from the nearest such coast – the north shore of Mare Frigoris. The Lunar South Pole is more than twice as far removed from the nearest such coast, the south shore of Mare Humorum.

Despite the advantage of more hours of sunlight, and eventually recoverable water ice, starting at either pole could be an industrial dead end.

Yes, access to water is essential, but most of us interested in lunar settlement, before the possibility of finding water ice at the pole became a common hope, were determined to launch lunar settlement anyway. We would harvest solar wind protons from the moondust and combine them in fuel cells with oxygen coaxed from the same soil, to make water and extra power.

Having to do this, despite the now-confirmed reserves of water ice at the poles, may be a good thing, as it will prevent the rape of water-ice for the production of rocket fuel, and thereby preserve it for future lunar settlement needs including agriculture and biosphere. Yes Liquid Hydrogen and Liquid Oxygen are the most powerful fuels now in use. But 1) we don't need that much Isp to rocket off the Moon, or to hop from here to there on the Moon, and 2) we should be more concerned with developing more powerful fuels anyway, including nuclear fuels.

The polar water ice is at cryogenic temperatures, and extremely hard. Harvesting it in darkness at the bottom of steep crater walls will not be easy, and unless done entirely robotically, could be a very risky occupation. That it will be easy to harvest is myth #2. Myth #1 is that the sunlight at the poles is eternal. Honest estimates are that sunlight at any one spot is available only 76% of the tie at the South Pole, and possibly 86% of the time at the North Pole. That means for 52% of the nightspan at the South Pole and 72% at the North Pole. We must still bite the bullet and learn to store dayspan power for nightspan use for 100% of the nightspan, a factor of 2 times as long at worst. Then we can go anywhere, including places where a more complete suite of mineral assets are available, including possible gas deposits elsewhere.

The critical role of basalt is so fundamental to success that we must rethink our destinations. **DDz/PK**

MMM #242 - FEB 2011

Telepresence-operated "Robonauts" will revise all "Scenarios"

By Peter Kokh

At first impression, those of us who want to see human frontiers develop "and prosper" on the Moon, Mars, the asteroids and elsewhere in the Solar System may think that the emergence of robonauts threaten that dream. But quite the opposite is likely. These "stand ins" will pave the way at far less expense,

We have already integrated "teleoperation" of equipment" into our expectations. Japan and Russia, as well as our own Carnegie-Mellon robotics team, have suggested that site preparation and many construction chores could save substantial amounts of time and money. It costs a lot to put a human on the Moon! Humans are most effectively assigned to chores that cannot be teleoperated. Teleoperated equipment will allow humans to go to the Moon to begin at once to do what only they can do.

Enter the "robonauts" and telepresence! Here the human controller on Earth "sees what the robonaut sees, feels what the robonaut feels." This is ideal for scientific tasks - for example, where it is not the size, shape or weight of a rock which is of interest, but its chemical-mineralogical makeup." Robonauts can collect samples of special interest, freeing humans of that tedious chore, so that when they arrive, they can examine a pre-selected collection, without wasting hours and days in field work.

Roboanuts do not need food, rest or relaxation. They can work around the clock, through a team of tele-presence operators on Earth. They do not get bored. Thus the quality of their work is more likely to be high. As to teleoperated equipment, there will be many chores which cannot be done into their manipulation tools, one of a kind chores, that could not be foreseen, or which will be so uncommon that it would not be cost-effective to further specialize those tools and programs. A robonaut with hands human-like in their degrees of motion, can use hand tools for a limitless list of special tasks. Robonauts can do things too dangerous or risky for human crews. T companions can relieve humans of all sorts of risky and tedious chores.

In his article "O'Neills High Frontier Revisited and Modified" blow, Dave Dietzler shows how the emergence of robotic technologies also radically changes that scenario of how solar power satellites will be produced and deployed. No need for hyper expensive Space Settlements, that could delay the construction of SPS systems by many decades. Humans will still be involved, in lesser numbers, with far lower thresholds of support.

To sum up, lunar resources are still a best bet to lower SPS construction and deployment costs, but cost of accessing those resources will fall by an order of magnitude or more by reducing the amount of human workers involved.

Consider that a lunar settlement can begin very small and grow as needed, module by module. In Contrast, a Space Settlement has to be built to a set size, whether it is occupied by a starter crew, or at full capacity. Space Settlements have a built-in high threshold, greatly exacerbated by the insistence on Earth-normal gravity levels. **PK**

To the reader: This above is not an official research program of the Moon Society.

Rather, this is a collection of MMM articles that relate to research that the MMM Editor feels must be pursued, and sooner rather than later, by entrepreneurs and academia, if not by NASA, which is hamstrung by non-germane political issues - if we are truly determined to see the Moon become a new human frontier, engaged in producing products and services of benefit to the greater Earth Econsosphere, which already involves $250 B in activities in Low Earth Orbit and in Geosynchronous Earth Orbit, an area 60,000 miles across. This "econosphere" will inevitably grow to include the Moon.

- Some of this research must be done in industrial lab facilities by professionals
- Some of it can be the subject of engineering design competitions.
- Some of the resulting technologies can be tested at one of the various Analog Research Stations.
- Some of it can be done by entrepreneurs hoping to find profitable terrestrial applications - "spin-up."

(example) http://www.moonsociety.org/publications/mmm_papers/glass_composites_paper.htm

It is of extreme importance not to wait for NASA or other space agencies to take the lead!

The goal is a brighter future for the vast majority of humans who will remain on Earth, and an open-ended future for those who chose to settle beyond. Editor