The Development and Realization of a Silicon-60-Based Economy in CisLunar Space

In Search of Plausible Results

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abstract: (keywords: silicon, Si-60, fullerenes, space economy, lunar economy, regolith mining).

This paper departs from past proposals which envision mining of Lunar regolith and ore seperation, oxygen recovery and smelting operations. Proposed is the concept that after oxygen the second-most valuable extract is Silicon which would be processed in Lunar foundries into Si60 and other Silicon-based Buckmisterfullerenes.

The potential applications and resulting space economy are exciting in their scope. Unfortunately the concept and its' applications are somewhat tenuous: this author is unaware of any attempt to synthesize Si-60 to date. However, on the optimistic side, Carbon is a close analog to Silicon with similar properties, such as a valence of four. Several laboratories around the world have produced families of fullerenes, reflecting various topologies.

A myriad of Silicon Fullerene Products would include cable, extrusions and structural products all produced on the periphery of earth's gravity well in lunar and lunar-orbital foundaries. A second tier of applications is expected from alloys and the doping of Si60 derivatives including new semiconductors, nanomachines and translucent / transparent glass.

The advantage of the lunar manufacturing plant is seen as significant to the development of earth-orbital space habitats, resorts and satellites of all types when compared to lifting costs from planet earth. The Silicon Buckminsterfullerene Economy is elaborated.

Lunar Regolith as a Resource

The space-mining literature is rich with proposals which envision some variation on the following sequence of processes:

- mining of Lunar regolith
- extraction of ore
- ore seperation
- processing into bulk metals
- oxygen recovery
- smelting operations

These visions are focussed on extraction of oxygen or metals and most frequently consider silicon to be a nuisance. Our industrial base has wide experience with Silicon in many forms, glass and semiconductors being prime examples. With a new model the extraction and processing of silicon could easily prove to be the cornerstone of the new economic frontier.

The Apollo Lunar missions have provided confirmation through rock samples that sufficient silicon exists in the lunar regolith so as to support glass production. Fully half of the Apollo 17 cataloged samples identified in a 1973 NASA publication[1] exhibit presence of glass beads, teardrops, *etc*. either superficially attached to a host rock or embedded within one. This demonstrates the relative abundance of silicon in processable form, so much so that, according to some, even the occasional meteorite impact leaves fused Silicon oxides strewn about. The mass fraction of the regolith assayed to date would place the presence of silicon to be approximately 21 per cent.[2]

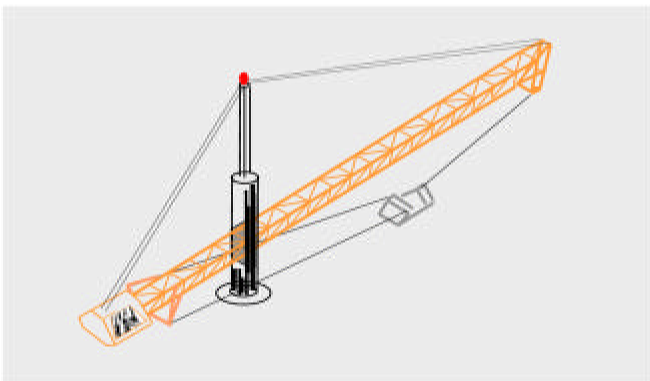

Figure 1. A Center-Pivot Lunar Slusher borrows from irrigation technology

Any processing of the regolith will certainly recover oxygen as that element constitutes over 60% of the regolith's mass[3]. Most of the processing operation will, in fact, be reducing metallic oxides to metals, and while some of the oxygen will be used for propellants a substantial portion will be migrated from rock to a carbon economy, or used to synthesize water when burned with hydrogen.

Extraction of the oxygen and silicon would therefore account for about 80% of the regolith mass leaving a high concentration of titanium, aluminum, magnesium, iron, and calcium.[4] These other constituents account for 20% of the mass and are, individually, only present in single-digit concentrations.

"Slag" is the leftover material from the mining operation and would normally be various oxides of silicon, something that we wouldn't have developed into a useful product. In our scenario, having removed

[1] Meyer, Charles, Jr., *Apollo 17 Course Fines (4 – 10mm) Sample Location, Classification, and Photo Index*.
[2] Haskin, Larry and Warren, Paul, *Lunar Chemistry*.
[3] ibid.
[4] ibid.

the silicon, the remaining "Slag" is a rich supply of high-quality residues which will be available for alloying into aerospace quality metals for vehicle frames.

Hydrogen and helium are available in the outermost volume of regolith, generally as a result of incident radiation. These gasses are generally mechanically entrapped within the "matrix" of the soil and leak steadily to hard vacuum. These gasses should be captured and condensed out during the initial disruption of the sediment as well as continuously during processing.

The hydrogen will be helpful in the processing of regolith, yielding water as a useful product. Electrolyzing the water will return the hydrogen to the process and free up the oxygen. Helium has utility as a buffer gas in breathing mixtures as well as a multitude of industrial applications.

Calcium is an eight per cent participant in the regolith, and is one requisite precursor for making concrete. There are numerous applications for this element some of which intersect with silicon.

Another mineral source which cannot be overlooked is the occasional stray asteroid. These derelicts are rich sources of all types of minerals, including rich organics. And if there is an ingredient deficiency on the Lunar surface it has to be carbon which was not even listed in assays of returned lunar samples. We should expect to import or synthesize carbon for use on Luna.

Carbon certainly cannot be exported from the moon until a substantial carbon source is available.

The Economic Lever

Given our current Newtonian transport systems it can be assumed that bulk commodities will be uneconomical to transport in space for some time. Ground transport will certainly be less expensive and yet quite costly until the infrastructure develops. In terran economies bulk transport favors water-borne shipping or railroads, dubbed "land-ships" by R.B. Fuller. Since water-based navigation is unavailable on the moon we will probably have to build the equivalent of railroads.

One way to reduce the need for bulk transportation is to process the bulk commodity and reduce it to a more compact form. "Adding value" moves such material from bulk commodity to valued product. Frequently the process of increasing the intrinsic value and complexity of a material reduces the bulk.

Processing the regolith will yield large quantities of cyogenic oxygen which will increase in volume and decrease by the mass of the seperated metals. If we make silicon the next objective, copious quantities will result, followed by large quantities of other metals. There are certainly many conventional uses for bulk silicon, usually in the form of sand or refined silicon crystal.

Silicon fullerenes, however, have the potential to be the value-added process that can move silicon beyond the usual bulk materials paradigm and into the high-tech, high-value marketplace. Much of this is speculative and each bit of progress should continued to be carefully studied. However, so many milestones have already been achieved that a momentum is building for the entire field of nanostructures and fullerenes and a cautious optimism is warranted.

Silicon Fullerene Fabrication Technologies

Initially the case for silicon fullerenes did not offer any cause for optimism. The persistent notion that silicon "ought to work" similarly to carbon was strictly intuitive. Such intuition is frequently flawed and further research was imperative.

The reasons it shouldn't work were compelling:

- Preliminary research disclosed no attempt to synthesize Si-60 to date.
- It is unclear whether the double bonds found in carbon are required for a stable fullerene, since silicon would seem to lack this feature.
- It is also not encouraging that the orbital of the p_π—p_π electrons is not as strongly coupled as those of the carbon atom and, therefore, might not be able to maintain the bonds between adjacent silicon atoms necessary to construct fullerenes.

- A semiconductor physicist asserted that the above point excluded the possibility of any fullerene constructs.

On the positive side of the opportunity ledger:

- Many examples of pentagonal and hexagonal structures based upon silicon exist, including Phenylcyclopolysilanes and Methylcyclopolysilanes.[5]
- As an extension are the heterocyclic compounds which demonstrate a symmetry through the interposed sequencing of oxygen, chlorine, *etc*. with the Silicon.[6]
- Diamond-like and graphite-like *allotropes,* which strongly resemble the carbon versions, exist.[7]
- Silicon is a close analog to carbon with similar properties, such as a valence of four. Chemistry texts would seem to confirm the notion that the similarities between carbon, silicon and the rest of the Group 4 elements in Mendeleyevs's celebrated periodic table are striking.
- Silicon Carbide, a collaboration of carbon and silicon, hints by its' very existence that something ought to work.
- Carbon Fullerenes exist.

And so do silicon and silicon carbide fullerenes. The experience of Msrs. Neudeck and Powell was that fullerene formation is a nuisance encountered during the fabrication of Silicon Carbide wafers and semiconductors.[8] The mechanism causing the unsolicited defect should be identified not just for elimination of the process defect but also for the potential of an efficient fullerene synthesis process. One man's "micropipe" irritant is another man's jewel of a fullerene.

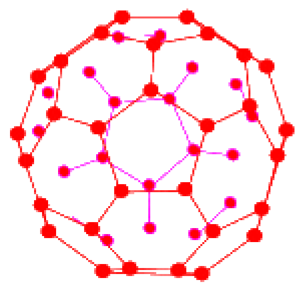

Figure 2. Coarse Depiction of a "BuckyBall" molecule

Other researchers have successfully modelled the molecular behavior of hypothetical buckyballs and fullerenes.[9] [10] [11] [12] [13] [14] Considerable efforts were made in an effort to predict the viability of silicon fullerenes, some results suggesting an unworkable idea and others, a robust molecule. Yet other research-

[5] Fred Armitage, *Inorganic Rings & Cages*, 1972, pg. 157-160. Had he extrapolated just a bit, he could have been the inventor of the Buckminsterfullerenes. He largely ignored carbon in this book in order to simplify the subject and avoid redundancy with the existing body of work.

[6] Op. Cit., Armitage, pg. 158.

[7] Op. Cit., Armitage, pg. 152.

[8] Philip G. Neudeck, J. Anthony Powell, *Performance Limiting Micropipe Defects in Silicon Carbide Wafers*.

[9] Harada, M.; Adachi, M., *Surfactant-mediated fabrication of silica nanotubes*.

[10] Bao-Xing Li; Ming Jiang; Pei-Lin Cao, *A full-potential linear-muffin tin-orbital molecular-dynamics study on the distorted cage structures of Si/sub 60/ and Ge/sub 60/ clusters.*

[11] *Electronic structure of some semiconductor fullerenes*, Aguilera-Granja, F.; Dorantes-Davila, J.; Moran-Lopez, J. L.; Ortiz-Saavedra, J.

[12] *On the fullerene structures of the Si/sub 60/ cluster*, Nagase, S.; Kobayashi, K.

[13] *An effective Hamiltonian study for the binding energies of large Si clusters (Si)/sub n/*, Oshiro, T.; Lutrus, C. K.; Hagen, D. E.; Jae Suk Lee; Sung Ho Suck Salk

[14] *Stability of medium size silicon clusters,* Jug, K.; Krack, M.

ers have tested the viability of fullerene creation for other members of the Group IV elements and the results are promising.[15]

These macromolecules have been synthesized in the laboratory, in direct application of the earlier models.[16] [17] [18] [19] [20] Several laboratories around the world have produced families of fullerenes, reflecting various topologies, processes and chemistry. Encouraging is that some processes easily yield very long molecules.

The entire field of fullerene production is still in the early stages, with carbon leading the pack. The climate is very similar to the early days of semiconductors and potential even larger. Semiconductors are an incredible set of technologies but they are seldom used in the bigger world of structural components, engine internals or mechanical parts except as control electronics.

Concurrent with the development of production methods for silicon fullerenes would be the crafting of attachment methods for industrial volume synthesis of composite parts. These attachment technologies would include molecular-level methods for welding and annealing nanotubes to each other as well as to "foreign" objects, such as silicon wafers.

In the cold, hard vacuum of space "cold-welding" may be an effective way to eliminate lots of fasteners and connectors. Silicon can be a component of a conductor, a semiconductor or an insulator, and attachment of these components to each other is vital.

Characterization of each fullerene product is essential for best determination of the scope of potential applications in space and on the moon. Such testing will offer up surprises such as the fact that graphite, a common lubricant, "*becomes an* abrasive *below 10-6 torr.*"[21] Which suggests that graphite is not appropriate for use as a space vehicle lubricant, opening an opportunity for a silicon-based lubricant.

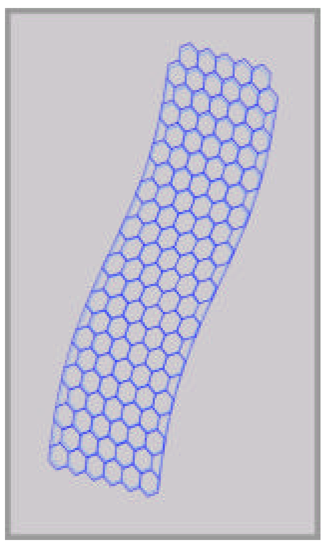

Figure 3. Coarse depiction of a Nanotube

[15] Leszczynski, J.; Yanov, I., *Possibility of the existence of non-carbon fullerenes: ab initio HF and DFT/B3LYP studies of the IV main group fullerene-like species*.
[16] Lin Hong-Ping; Mou Chung-Yuan; Liu Shang-Bin, *Formation of mesoporous silica nanotubes.*
[17] Ming Zhang; Bando, Y.; Wada, K., *Silicon dioxide nanotubes prepared by anodic alumina as templates.*
[18] Adachi, M.; Harada, T.; Harada, M., *Formation of huge length silica nanotubes by a templating mechanism in the laurylamine/tetraethoxysilane system*.
[19] *Electronic and structural properties of Si/sub46/: a novel solid of silicon fullerenes*, Saito, S.; Oshiyama, A.
[20] *Synthesis of Fullerenes in Low Pressure Benzene/Oxygen Diffusion Flames*, Hebgen, Peter; Howard, Jack B.
[21] *the case for going to the moon*, Neil P. Ruzic, pg 24.

Bulk Silicon Products

One type of bulk silicon product are those which are principally concerned with static mass. These would take the form of sand and crushed rock and be used for ballast, backfill, radiation and micro-meteorite buffers, concrete and the like.

Another type of bulk silicon would center around paving. Since the lunar surface isn't blanketed by water or carbonaceous soil the direct application of heat to the lunar surface will extract some oxygen, fuse the regolith, and increase the density and durability of the surface, all in one continuous process. This *in situ* operation would level, smooth and compact the soil in a mostly automated process. Fused silicon aggregate wouldn't require the volumes of water, mostly irrecoverable, that concrete does.

Silicon feedstocks will be required to fill the pipelines with silicon for semiconductor crystals, silicon oxides for processing into various glass products, silicon for processing into fullerenes and low-temperature, graphite-type lubricants such as $CaSi_2$.

Intermediate Silicon Products

A myriad of silicon products are components of more complex assemblies of parts. Intermediate products buffer, enhance or enable other technologies. These would include cable, extrusions and structural products all produced on the periphery of earth's gravity well in lunar and lunar-orbital foundaries. A second tier of applications is expected from alloys and the doping of Si60 derivatives including new semiconductors, nanomachines and translucent / transparent glass. Industrial components would also include the development of advanced alloys[22] which spawn yet additional product possibilities.

A new class of parts would cage liquid crystal within fullerenes allowing complex structures with useful optical properties. Others would capture ferro-magnetics and superconductors within the cage.

In addition to conventional fiberglas production fullerenes may be spun as insulation. Fibers, threads and filaments can be used to reinforce concrete[23] and be used in applications appropriate to Kevlar and the like. Composites are already widely used in airframes and fullerenes will probably compete for local, lunar applications.

Industrial products have a large content of films and plating. Silicone fullerene films exhibiting various characteristics are actively under development.[24]

Aerogels are an *existing product* available in both carbon and silicon flavors which are in search of applications.[25] *Foams* of various densities and properties will be ubiquitous.

High-Performance Products

Silicon Carbide is a very intense application arena just now. A new silicon carbide in the form of a fullerene is being fabricated and studied which features an inner C_{60} molecule bonded to an outside shell of

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[22] *Development of Advanced Alloys using Fullerenes*, SIMS, J.; WASZ, M.; O'BRIEN, J.; CALLAHAN, D. L.; BARRERA, E. V.

[23] Corley, Gene and Haskin, Larry A., *Cement and Concrete*, pg. 297.

[24] Ciullo, G.; Moratti, M.; Toccoli, T.; Iannotta, S., *SiC growth on Si(111) from a C/sub 60/ precursor: a new experimental approach based on a hyperthermal supersonic beam*.

[25] *Structure and performance of carbon aerogel electrodes*, PEKALA, R. W.; MAYER, S. T.; POCO, J. F.; KASCHMITTER, J. L.

Si_{60}.[26] Semiconductors fabricated on the surface of an Si-C wafer promise to improve performance and durability.[27]

A close cousin to the fullerenes are the *diamond-like allotropes*. These are typical for the Group IV elements: *"The diamond structure is adopted by silicon, germanium and the grey-, or α-form of tin."*[28] Fullerenes have been suggested as a handy precursor to fabricate diamond-like materials under relatively low pressures.

Telecommunications and computational circuits are continuing to shrink to ever-smaller geometries. The feature sizes are approaching a point where "quantum effects" dominate the operating physics of the circuits. Fullerene structures will add a new dimension to semiconductor physics and technologies.[29]

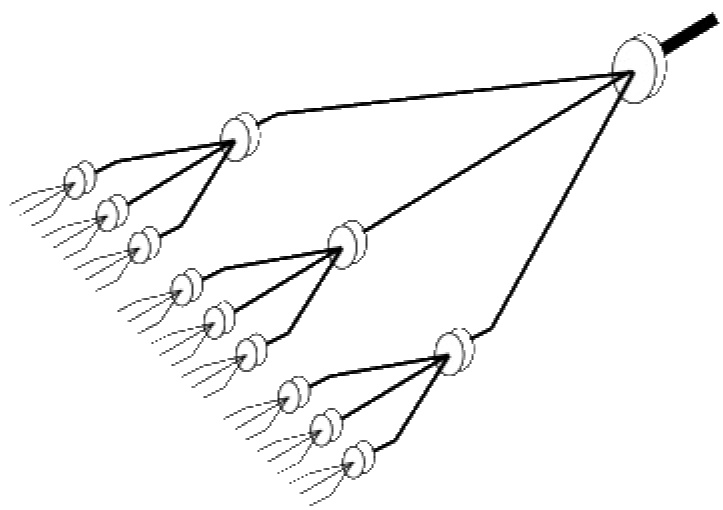

Figure 4. Fractal Fabs start with NanoMachines

Nanomachines can change the scale of application and can be used in the future to stitch nanotubes and buckyballs together into larger assemblies. NanoMachines themselves will be based on fullerene structures. These products will often be built on fullerene structures and will stitch together more complex assemblies. Versions of these will resemble computer components; state and Turing machines will follow pre-programmed operations.

Many useful programmable nanomachines can be built without implementation of self-replication. Intelligence will be incorporated into components such as self-annealing silicon "fabrics".

Nanomachines can be designed to patch nanotubes, bundle, weave and braid nanotube strings. In recursive Escher fashion doing it again and again and again, in successively increasing caliper. It's a fractal universe. After the nanotubes have been assembled into a visible thread conventional machines can weave the product into larger, commodity sizes.

Optical Components with high utility would include fiber optics, optical switches, optical logic, light-emitting diodes (LEDs) and solid-state lasers.[30] [31] [32] [33] Optical features of silicon, carbon, silicon carbide and heterocyclics will be selected for their optical and spectral characteristics.

[26] *(SiC)/sub 60/, an idealized inverse superatom?* Osawa, S.; Harada, M.; Osawa, E.; Kiran, B.; Jemmis, E. D.

[27] *Ab initio HF and density functional theory studies of C/sub 60/@Si/sub 60/*, Jemmis, E. D.; Leszczynski, J.; Osawa, E.

[28] Op. Cit., Armitage, pg. 152.

[29] Coaxial nanocable: silicon carbide and silicon oxide sheathed with boron nitride and carbon, Zhang, Y.; Suenaga, K.; Iijima, S.

Architectural Components will include specialty cable, panels, i-beams, airlocks, service cores, *etc*.

Refractory Components will be used for reaction jets and booster engines for probes, satellites and launchers. Magneto-HydroDynamic generators (MHD) for local electric power would use a family of refractory components. Pads, disks and drums for brakes, electric clutches, abrasives, nozzles and turbine blades are obvious candidates for the refractories.

Ceramics are an intriguing potential target for application of silicon and silicon fullerenes. Such exotic and conventional ceramics would find their way into electronics packaging, electrical insulators and even cooking ware.

Advanced propulsion systems would not only incorporate silicon fullerene components but may actually use fullerenes as the propellant.[34] [35]

Constraints on Production

The high level of capitalization required for projects in space is a definite handicap. In addition to the usual funding of production facilities the transport and service costs from earth to the moon must be covered. Investing in lunar facilities is a high-risk to a risk-averse world. The very extraterrestrial nature of this venture is an extreme form of "offshore investment".

The location of the plant requires on-site manned service facilities to address the logistics of service. The remote location makes recovery of defaulted assets nearly impossible. Their value is high just by virtue of their location in space and that they represent useful mass times orbital velocity.

The operating environment of the moon may offer production advantages but the same will also create new complications and hazards to operating a plant. Hard vacuum encourages dust accumulation on exposed surfaces.

Advanced Production Methods

Novel processes will be developed which exploit the environment unique to space. These processes will be novel for conventional materials and nearly unrecognizable for the fullerenes. The operating environment of low gravity, zero gravity,[36] vacumm and radiation will certainly bring new possibilities to manufacturing.

Vacuum processing, for example is particularly valuable for plating and other processes which require low contamination and molecular interference. Space is a vacuum chamber of unlimited dimension.

Yet another constraint which impacts the production process is energy, and using minimum energy for adding value will obviously minimize costs. It is possible that some fullerene processes will resemble a brewery, producing batches of product in vats over a protracted interval. This is a matter of exchanging time for energy.

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[30] *Preparation and properties of silica films containing fulleropyrrolidines*, Maggini, M.; Scorrano, G.; Prato, M.; Brusatin, G.; Guglielmi, M.; Meneghetti, M.; Bozio, R.
[31] *New fullerene-based mixed materials: Synthesis and characterization*
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[32] *New fullerene-based mixed materials: Synthesis and characterization*, McBranch, D.; Kohlman, R.; Klimov, V.; Grigorova, M.; Shi, X.
[33] *Feasibility of fullerene thin films for high-speed all-optical switching*, LEE, HOWARD W. H.; HUGHES, ROBERT S., JR.; DAVIS, JEFFREY E.; MCONAGHY, CHARLES F.; HAMZA, ALEX V.; BALOOCH, MEHDI
[34] *A High Thrust Density, C60 Cluster, Ion Thruster*, Hruby, V.; Monheiser, J.; Kolencik, J.
[35] The NASA-JPL Advanced Propulsion Program, Frisbee, Robert H.
[36] *Formation of Carbon Nanotubes in a Microgravity Environment*, Alford, J. M.; Diener, M. D.

The economics of Luna vs. Terra

The fact that mankind has no current presence on the moon is a testament to the cost of getting there. The Saturn V is a very expensive vehicle, fully laden with cryogenics, to discard on a round-trip to the moon. Lifting costs from planet earth basically make routine traffic in CisLunar space prohibitively expensive.

The crowded equatorial geosynchronous orbit points to our willingness to invest resources when a benefit and a return on investment can be demonstrated. Delivering a payload on a *one-way* trip slashes the scale of the launch package. The resulting launcher is still large and expensive.

Building earth-orbital space habitats, stations and resorts is likewise expensive, lingering around $10,000 per pound.

It is possible that the first best market for lunar commerce may be the synchronous communications satellites. Substantial products can be provided from the lunar plant which should be competitive with earth-launched satellites and modules.

One early conclusion is that making the moon as self-sufficient as possible, as soon as possible, is a minimum requirement towards making lunar commerce viable.

It is clear that "bootstrapping" of the lunar infrastructure is imperative. Automation of processes may be the only affordable option with robotic facilities sent to the moon on a one-way trip.

Some products may not be exportable from the moon due to scarcity of minerals. A deposit may be required in the form of the scarce material, equal to or exceeding that required for the rare content of the product being purchased. Every resource will certainly be tightly managed and optimized. To reduce ferro-magnetic mass the powergrid, for instance, should probably operate in the 400Hz domain. This has the side-effect of immediate compatibility with aerospace vehicle systems.

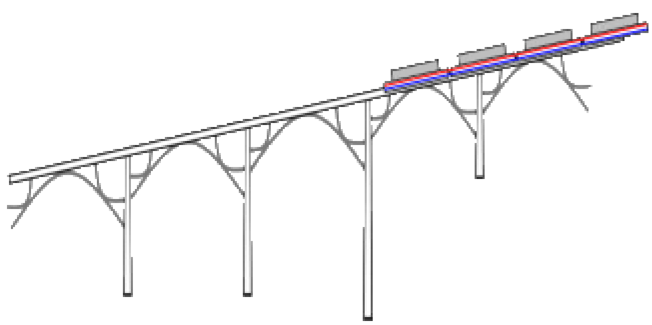

Figure 5. Lunar transportation will be a huge customer

The Silicon Buckminsterfullerene Economy

Current efforts in nanotechnology and fullerenes are numerous and international in scope. Carbon-based fullerenes will have huge payoffs in the next round of the technology-driven economic cycle. Entirely overlooked in these efforts is the promise of silicon and other group-IV tetrahedral elements to make similar strong contributions, particularly in the Lunar Infrastructure in a place rich in silicon and berift of carbon.

Potential high-performance products and intermediates offer the plausibility of a vigorous economy.

Fundamental operations required to convert regolith to refined commodity will have to be delivered from earth for the first generation. These machines will be *mostly* autonomous with some direction from a terrestrial command center.

A substantial portion of the first generation output will be required to implement a number of second generation production plants. Geometric growth of small, distributed facilities will result in a mix of generations. The age of a facility will not be a factor until enough capacity is on-line for competition to set in.

The foundation of the Lunar Economy would start out in the field, in small encampments. Installation of *large*, *single-function* mining, ore seperation and smelting equipment for generation one would be sequential. Smaller capacity equipment, capable of mining and processing ore from front to back in a single system are also a possibility. Both approaches to plant will probably occur simultaneously from competing firms.

In the next round of infrastructural development a divergence and specialization of function begins to take hold. Foundries, rolling and stamping mills specific to each metal are shipped to the sites, along with wire and extrusion plants. These are likely not evenly distributed among the mining camps. Cooperatives and other economic devices will be developed to share some of the more costly production plant. And with the various metals and forms some specialization sets in.

Heavily automated machine shops will produce a wide range of processing machines based on terrestrial designs. The automation allows for *custom mass-production* of large quantities by virtue of reliable repeatability.

The businesses of logistics will advance from small shuttle services to more advanced facilities such as elevated monorail for heavy hauling, the off-world railroads of the 21st century. These rails will allow for the cooperatives and the larger plants to be fed stock from larger regions, causing some encampments to grow more rapidly to support the growth.

The fullerene foundries would be installed in time to participate in the wave of second generation of mining and processing equipment. These new facilities are almost all home-grown with only highly-precision components being imported from earthside.

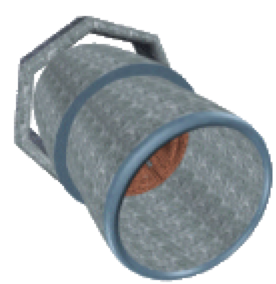

Figure 6. Refractories and Ceramics for Thrusters

Market segments and applications which will consume silicon or deliver silicon are numerous:

* Abrasives * Actuators * Adhesives * Aerogels * Breathing Gasses * Building Construction * Cable * Ceramics * Chemical Plants * Composites * Concrete * Custom Alloys * Commodity Storage * Computers * Earth-Moving Equipment * Engines * Erecting Structures * Extruded Rail * Fabrics * Fiber * Fiberglas * Filaments * Films * Filters * Foams * Glasphalt * Glass * Hardware * Industrial Diamond * Industrial Gasses * Launch * Lenses * LightPipes * Lubricants * Machine Tools * Magnetics * Mag-Lev Launch * Motors * NanoMachines * Optics * Optoelectronics * Pipelines * Piping * Plating * PowerPlant * Rail Lines * Refractories * Roadway * Roadway Development * Sand * Satellite Manufacturing * Semiconductors * Silicon Carbide * Soil matrix * Structural Components * Structural Modules * SuperConductors * Switches * Tankage * Trace Mineral Fertilizers * Transport * Vehicle frames *

The implementation of this sample of applications form an infrastructure. The interaction of these infrastructural components is called an economy.

In Summary:

The intent of this paper was to convey some of the rich texture of silicon applications, both exotic and conventional. Since silicon is accessible on the moon in vast quantities then future processes should make silicon a resource instead of a waste. The potential silicon economy is as multi-faceted as a buckyball itself.

Lunar processing increases the Added-Value of silicon creating products for local use and export to lower orbit. Silicon Fullerene technologies could "bootstrap" and sustain a Cis-Lunar economy

NASA has committed to advancing nano- and fullerene-technologies as key elements in our continued development of space.

Since silicon is the most abundant mineral available to mankind on the moon let us, quite literally, MAKE THE MOST OF IT!

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Curriculum Vitae

A nuts and bolts technologist from 'way back, he designs and develops products with electronics or intelligence content for the industrial world. Raised to be a generalist and an artist in a long line of artists he is comfortable working in petrochemical, avionics, mining, systems peripherals, industrial automation and the like. His customers have produced his designs in oil well controllers installed on five continents, avionics flying in commercial and military fleets worldwide as well as the President's Helicopter Fleet. These devices are often, although not exclusively, embedded controllers.

His technical passion is *lost and ancient technologies*, a field which he characterizes as "unearthing architecture". His efforts in this arena include cross-disciplinary application of "mis-placed" technology.

He holds a Bachelor's degree in math and computer science, having grown up with computers since the sixties while still a teen-ager.