**Dueling Infrastructures**

**for Deep Space** **Refueling**

**and Space Settlement Destination**

Dave Dunlop

May 2, 2017

Infrastructure is fate. Once in place by intention infrastructure enables some things but often at the same time provides unintended constraints. A highway or rail line enables movement in one direction but also divides the environment inhibiting access in the other direction. Infrastructure stimulates so much secondary development that the cost of changing it as time progresses, is most often rationally impossible.

For better or worse economically one is simply stuck with the infrastructure you’ve got. Natural disaster and war sweep away at unimaginable cost the strictures of historic economic rationalism. The aftermath of such destruction is a chance to create new infrastructure.

**Rocket Fuels and Infrastructure**

Much of the infrastructure of the rocket business and large rocket motors is based on cryogenic fuels including liquid oxygen and also frequently liquid hydrogen. Chemical propellant commonly used include liquid oxygen (lox) and JP4 or (lox and alcohol) with an isp range of from 210 to 250.

(1) The Falcon 9 Merlin vacuum engine using lox and kerosene (RP1) has demonstrated an isp of 342.

(2) It also has a BE-4 engine using liquified natural gas and lox producing 550.000 lb of thrust and which will be used on both it New Glenn Rocket and the ULA Vulcan rocket.

(3) The venerable Russian Soyuz RD 107/108 rocket engine burns lox and kerosene with a vacuum isp of 320.6.sec. while their RD-0124 stage 3 engine lox/kerosene has a vacuum isp of 359 sec

.(9). Long March YF 25 engines have used UDMH fuel with N204 oxidizer producing 289 sec isp. (10)

The gold standard of chemical rocket fuels with the highest specific impulse is liquid oxygen and hydrogen. The Blue Origin company has produced a BE-3 engine using lox and liquid hydrogen to produce 110.000 lb of thrust for the New Shepherd rocket

(3) The ULA RL10 upper stage engine uses lox/LH2 with an isp of 465 for its Delta IV and Atlas V launches.

(4) The liquid oxygen -liquid hydrogen Aerojet Rocketdyne RS-25 space shuttle main engines has an isp of 452. (5) The largest liquid hydrogen production facilities in the world were constructed at Cape Canaveral. The Air Force also uses lox-liquid hydrogen for its expandable rockets the Atlas V and the Delta 4 which it also launches from the huge Vandenberg AFB complex in California. The Japanese are developing a Lox/LH2 LE-X 300.000 lbf thrust engine for the H-III launcher that has 435 sec. isp.

(6) The Russians have copied the RL1O design with the RD-0146 engine.

(7) ISRO successfully tested its cryogenic stage C25 for the GSLV Mk III vehicle in February 2017 for the flight duration thus preparing the way for a flight demonstration.

(8) The Chinese Long March Y 75 engine for the CZ 3A launcher burns lox/lh2 and produces 17 tons of thrust with an vacuum isp of 438 sec. (10)

Given the difficulty of mastering the reusability of rockets the industry,, from the time of its creation, has accepted the insane expense of throwing away vehicles which routinely cost tens of millions of dollars because of the importance of national defense systems. Satellites to observe an enemy, to warn of possible preparations for war, or even to detect the beginning of attack are worth the insane expense of expendable vehicles. Even that is less expensive than the humiliation, destruction and death of military defeat.

All this infrastructure and insane expense has become the routine experience of the military and science establishment relying on expendable rockets in operations near the Earth.

But now a revolution is in full force as a result of the revolutionary development of expendables rockets Falcon 9 ( by Elon Musk’s Space-X and New Shepherd by Jeff Bezos Blue Origin companies. Both these reusable vehicle use Lox and RP1. Their successful demonstration has forced the heritage contractor ULA to also undertake modifications of its Delta IV and Centaur upper stage to produce a Vulcan Rocket with a recoverable lower end first stage.

But Elon Musk in particular is focused, perhaps obsessed with getting humans to Mars and settling the Red Planet with a million people over the course of this century. He rolled out his scheme as the IAC meeting in Guadalajara Mexico. Mars unlike the Earth’s Moon has plenty of frozen volatiles on and under its surface. It has carbon dioxide ice in its polar regions, and permafrost under its frozen landscape. Remote sensing data has also revealed the presence of buried glaciers in the near subsurface. Mars atmosphere is only about 1 % of the Earth’s atmosphere at sea level and it is composed of nitrogen and carbon dioxide.

In the early 1990’s Robert Zubrin proposed the use of a long familiar chemical process the Sabatier reaction to transform the CO2 atmosphere of Mars into methane rocket fuel. The hydrolysis of water ice could provide the liquid oxygen. To use the hydrogen as fuel which requires sophisticated and expensive complex equip would not be economically feasible. Mars is so distant and it is so expensive to land massive amount of equipment that to creation a hydrogen fuel infrastructure is outside of what can be afforded. But Zubrin’s proposed system could be done compactly by a space ship design to refuel itself from the atmosphere of Mars itself.

Elon Musk’s obsession with Mars therefore must be enabled by his use of a fuel production strategy taking advantage of Mars resources. Kerosene fuel is not an option on Mars and Hydrogen fuel is not an option on Mars. He therefore must create a new infrastructure on Earth for a system architecture that can get to Mars and refuel on Mars.

Elon Musk is a very talented and innovative economic disruptor. He is willing to disrupt and or destroy the previously dominant infrastructure if he can see an economic payoff in creating something new. So the battle is joined with his introduction of both reusable rockets and his requirements that these reusable rockets use liquid oxygen and methane versus those that would use liquid oxygen and hydrogen, (namely his heritage competitor ULA which is the primary vendor for the Air Force and the NASA SLS-Orion system).

The battle is also mirrored in the conflict between scientists and entrepreneurs that want to take the much lower cost campaign to return human to the surface of the Moon permanently and complete the exploration of that vast terrain equal in area of all of Australia and Africa combined and those who want to put people on Mars to both explore Mars whose surface is equal to all the land surface on Earth and to discover if indigenous life ever evolved when Mars was a much warmer and wetter planet.

Since about 2008 the discovery of large amount of water ice on the Moon also presents the prospects of producing liquid oxygen and liquid hydrogen fuel on the lunar surface. What remains to be demonstrated is whether there are ice deposits sufficiently abundant to be operationally useful sources of propellant. Yes there are solar wind deposited volatiles including OH, hydrogen, and CO2 on the lunar surface but their use is constrained by the amounts that can be operationally useful.

Yet another option is also foreseeable. Accessible Near Earth Carbonaceous Chrondrite asteroids might also supply the hydro carbon fuel and the oxygen required for fueling space craft both in cislunar space and to and from the lunar surface.

Largely unnoticed but more revolutionary is the patented system developed by Dr. Peter Schubert to use the lunar regolith as the feedstock for a supersonic dust roaster and “element separator”. This system would use solar energy on the lunar surface to break on the chemical bonds of the silicate and metal oxides of the lunar regolith to produce not only oxygen but many other essential elements including silicon for solar cells, iron, magnesium, aluminum, and titanium.This system might be also used on other airless bodies such as Near Earth Asteroids, the Martian Moon Phobos and Deimos, and perhaps with modification even in the near vacuum conditions on the top of Olympus Mons which is in essence sticking out into space.

So there is a struggle to define and develop the fueling infrastructure for deep space. Will it be dominated by the easy score of methane from Mars atmosphere as Elon Musk desires for his Martian enterprise (or similarly for Blue Origin?) or will it encompass the range of options from lunar ice mining, to the processing of carbonaceous chrondrites, to the use of the “dust roaster element separator system patented but not yet matured or demonstrated by Peter Schubert?

**This struggle for infrastructure is also a struggle of economic models**. Elon Musk’s economic model is based on sustaining a transportation industry transporting human to Mars over a period of decades. While moving a million people to Mars requires a big space transportation enterprise Elon has not described what infrastructure will be available on Mars to receive and support this population, how much investment will be required to produce this space settlement, how it will be created, or more importantly what return on this investment that can be expected by investors on Earth. So far we haven’t seen a credible economic case for Mars. Only at the IAC program in Adeleide Australia present a terrestrial transportation model baed the BFR that would provide an economic basis for the implementation and sustaining use of the BFR infrastructure.

Even the Bob Zubrin’s popular and widely read book the Case for Mars makes a case for the importance of Mar’s exploration both as destination of intrinsic scientific interest but also as a compelling force on the Earth’s society and political psychology. It does not provide an economic model that provides a return on all the investment it takes to produce a sustainable human presence on Mar. This is a challenge that must be faced for advocates of human space settlement such as the National Space Society.

This same economic challenge exists for the economic development of cislunar space and the surface of the Moon. There however we have a much richer set of alternatives and proposals.

First the Moon is closer to the Earth and cheaper to get to in terms of the time and support and the logistics systems needed. The Moon is only two and half days away using a Hohmann transfer orbit. For non-human logistics to the Moon Low energy trajectories using weak stability boundaries may take many months for supplies which is perhaps more comparable to Mars logistics than many would at first assume. Still the Moon has many price advantages due to its proximity to Earth but especially to the potential markets that Earth represents.

1 Space Tourism: Many people may want to visit the Moon and Cislunar space. Several companies have invested in reusable space ships which can make a profit transporting tourists with a high flight rate just like the aircraft industry operates.

2 Scientific Investigation: The Moon like Antarctica is a fitting location for Science bases.

Thousands of scientists work during the summer in Antarctica in many bases supported

by a large number of countries. Antarctica is the model of science base permanence in the

face of an extremely remote and harsh environment.

3 The Moon can produce rocket fuel and support transportation hubs in E-M Lagrange points

and perhaps even for satellite servicing as well as transportation requirement from point to

point on the lunar surface.

4 Cislunar space can be a focus for mining of minerals from accessible (operationally useful)

asteroids and asteroidal materials on the Moon may provide a rich surface mining industry.

Schubert’s dust roaster element separator can mine the entire regolith blanket of the Moon

as a pre-pulverized feedstock for surface manufacturing.

5 Using mining feedstocks the Moon and cislunar space can become industrialized and a

location for manufacturing.

6 New Satellite based services can service the entire global population of 7-8 billion with

information, geo-positioning, telemedicine, tele-education, web access, banking, and other

business and social communication services. Extending these services to the several

billion people now lacking them will provide a huge leverage in the development of the

human capital of the planet and to the human economic creativity that represents.

7 Space Solar Power satellites can become a primary clean energy source for the global

economy supplanting environmentally unsustainable fossil fuel utilizations and **providing**

**growth into an existing multi-trillion dollar industry that faces demands for energy**

**well beyond the capabilities of other non-fossil fuel alternatives.** It is this large existing

energy market on Earth that can provide the pragmatic returns on investment and growth

potential to transform the Earth economy and provide a sustainable civilization.

There is to the best of my knowledge no mature economic model that integrates the

economic growth potential and return on investment of this expanded cislunar economy.

with its diverse elements each of which represents the potential for a return on investment

due to the market for goods and services that the Earth represents. Each of these elements

to some extent interacts with the other elements so while there is confidence in business

models for single elements the full synergy of these elements is most likely underestimated.

But we can roughly estimate that the global economic growth potential is several times the

current size of the Earth’s economy due to both the population increase but also the

increase in individual energy consumption and economic productivity that space based

energy materials, and manufacturers will enable. If the global population achieves North

American standards of energy consumption and productivity the global economy would

increase five and a half times. So at the end of this century a global population of 11 to 12

billion may exceed ten times the economy of the beginning of this century.

That is also the key to the development of Mars. The economic burden of going to Mars

even for the richest country to day is formidable and unrealistically uncertain. At the end of

this century the economic burden of Mars settlement will be much less of a practical barrier

because much of the infrastructure and technology developed in cislunar space will also

apply to the Mars system. What will be gained on the Moon and in Cislunar space will be the

experience of creating additional built environments in deep space.

Designing for the requirements of not only our species but of the multiple species on which

we depend is a challenge that has not been realistically faced. Cislunar space is where we

can truly begin. The bold but premature ambition of Biosphere Two demonstrated that the

complexity and sustainability of artificial biosphere was not a simple or easy proposition.

We have barely scratched the surface in that endeavor. In addition to the economic and

transportation challenges of Mars and the harsh environment of Mars to immediate survival

is the creation of built environment on and above the Martian surface that can provide a

sustainable biosphere of Terrestrial evolutionary heritage. Commercial fusion technology

would certainly improve the odds of meeting the demands in that distant and cold location.

**If the real reason to go to space is to make money then the Moon has a much**

**stronger near term case than Mars.**

ULA has promoted its Space 1000 economic model. This is similar to that espoused by USC Professor James Wirtz. Professor George Sowers, with the Colorado School of Mines has also advocated for this ramp-up in human presence, during his tenure at ULA.

Jeff Bezos also has a vision of the industrialization of cislunar space as the basis for his

Blue Origin enterprise in rocket transportation and the shifting of mining and manufac turing off the Earth.

Companies such as the Shackleton Energy and Off World Consortium, and Moon-X are

based on the development of lunar resources. Deep Space Industries and Planetary Re sources are focused on the utilization of asteroidal resources. Made in Space is focused on in-space manufacturing.

**The arguments about fueling infrastructure are quite significant for the economic**

**competitors ULA, Space-X, and Blue Origins but also international partners**.

ISRO has worked to master Lox Hydrogen propulsion for the upper stage of their GSLV. The Japanese have also mastered Lox Hydrogen propulsion hardware on their H-II sys tem and evolving H-III system. This is a factor as well for the Ariane Space vehicles.

I expect the resolution of this commercial competition of dueling fuel infrastructure will be a

fueling architecture that preserves Lox Hydrogen because ice which is useful for shielding

and life support can be converted to Lox Hydrogen with solar power. This can continue to

use the the sunk investments of Lox Hydrogen at Kennedy and Vandenberg as well as

those of foreign partners. It is something that ULA is planning for its fueling depots and

which can be used by some key international partners. But other hydrocarbon propellants

maybe produced from lunar and asteroidal sources.

The key bulk commodity is oxygen and that is a feedstock where Peter Schubert’s system

can serve all destination and customers from asteroids, on the lunar surface, on Phobos

and Deimos, and on Mars itself. Nano particles of aluminum and magnesium can also

provide propellants in a slush oxygen vortex system. Very high specific impulse ion

engines can also provide a significant change in the travel times and supply chain to and

from Mars. Implementing a methane production system on Mars is something that can be

developed as an orbiting infrastructure is developed to enable further human exploration,

settlement, and economic and industrial development.

**The most sensible solution is an all of the above infrastructure that provides many**

**potential transportation fuel paths forward.**

*An integrated Moon First Path to Mars must provide an infrastructure that is not primarily driven by corporate gaming and competitive advantage to one company or one destination. We need to maintain and create an all of the above options infrastructure to continue moving forwar*d. It is a serious mistake to adapt a constraining infrastructure targeting just one strategic destination where there are a variety of destinations and environments to explore.

**The first priority is to create a sustainable civilization on Earth that optimized**

**individual human and economic potential.** That accomplishment will enable the

ambitions for the Moon’s settlement and development and Mars settlement and

development and other deep space destinations among the asteroid belt as the evident

beginnings of being a truly space faring species with a sustainable biosphere.

(1) https://history.nasa.gov/conghand/propelnt.htm

(2) <http://www.spacelaunchreport.com/falcon9.html>

(3) https://www.blueorigin.com/technology

(4) <https://forum.nasaspaceflight.com/index.php?topic=30910.0>

(5) https://en.wikipedia.org/wiki/Space\_Shuttle\_main\_engine

(6) https://forum.nasaspaceflight.com/index.php?topic=30910.0

(7) https://forum.nasaspaceflight.com/index.php?topic=30910.0

(8) <http://www.isro.gov.in/update/18-feb-2017/isro-successfully-tests-its-cryogenic-stage-c25-> gslv-mkiii-flight-duration

(9) <http://www.spacelaunchreport.com/soyuz.html>

(10) <http://www.spacelaunchreport.com/cz.html>