Dual Use Technologies for Self-Sufficient Settlements: From the Ground Up

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To become self-sufficient, remote communities must harness energy native to their environment, and possess conversion technologies to transform raw materials into finished goods. This paper presents new, dual use thermochemical conversion technology which can be used to produce multiple output streams from biomass for terrestrial applications, and which is being developed to produce multiple output streams from regolith for lunar settlements. Both programs are funded, the first by USDA and DOE, and the second by NASA. From biomass, a farm or village can produce the following, in increasing order of difficulty: heat, mineral ash, biochar, electricity, ethanol, and nitrogen fertilizer. The mineral ash can be further processed to produce photovoltaic-grade silicon. The biochar is a carbon negative soil augmentation, and together with fertilizer, can help grow more biomass. Ethanol can be used as a vehicle fuel, and as a libation. There are four patents pending on this biomass-to-energy work, which is based upon three patents already granted on regolith-to-metals processing in space. Recent technical publications outline how to form these into solar cells in situ. A major milestone in small-scale biomass power generation was achieved in August 2010 when the alpha prototype met all air pollution limits imposed by the EPA. This technology is ready to commercialize for combined heat and power plus biochar; with ethanol, fertilizer, and PV silicon to follow in another two years. The synergies between terrestrial and space technologies is sufficient that improvements on earth will help advance the technology readiness level for the first lunar base. In this paper, the technologies are presented, compared, and mapped to self-sufficient settlements built from the ground up.

Nomenclature

ECLSS	=	Environmental Controlled Life Support System
in situ	=	being or occurring at the place it normally occurs
ISRU	=	in situ resource utilization, or "living off the land"
ISS	=	International Space Station
MT	=	metric ton = 1000 kg - approximately equal to an English ton (2200 pounds).
regolith	=	pulverized rock dust
SBIR	=	Small Business Innovative Research – modest-sized research grants to small businesses
TRL	=	Technology Readiness Level (scale from 1 to 9 increasing in commercial availability)

I. Introduction

Heat transforms materials. Thermochemical conversion is a straightforward means to produce valuable products from readily-available raw materials and from waste streams. This paper outlines a step-wise development, already underway, to develop dual use technologies for use on earth and in space.

Figure 1 shows a full-scale working prototype of a system which processes wood waste and agricultural residue into electricity and sensible (useful) heat. The system processes about one MT per day of woody or fibrous organic matter, converts it to a "syngas"(hydrogen plus carbon monoxide), which is then used as a gaseous fuel in a generator set to produce continuous net electric power at a rate of 20 kW. The solid effluent is a benign, silica-rich mineral ash plus, when the feedstock is dry, a pure carbon "biochar" useful for soil augmentation. Air emissions meet US and Illinois EPA standards. Future modules which can be added to this platform technology include production of ethanol (from syngas) and nitrogen fertilizer (from electricity).

Figure 1. Farm-scale biomass-to-energy converter.

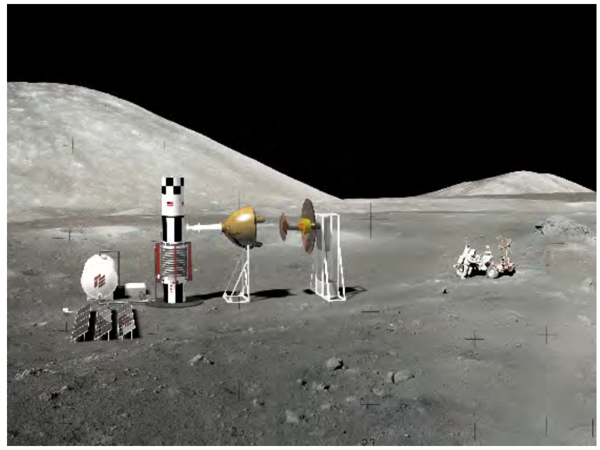

Figure 2. Lunar factory for oxygen and metals.

Figure 2 shows a combined oxygen and metal extraction facility. The patented thermochemical conversion processes[1,2,3] of this apparatus were the inspiration for the biomass converter of Fig. 1, for which there are four patents pending. The oxygen extraction portion of the lunar facility of Fig. 2 is funded by NASA through the Small Business Innovative Research (SBIR) program, which is presently in Phase II with total funding of $700,000. A patent[4] on this novel means of oxygen extraction has been allowed by the US Patent and Trademark Office, and should be issued by mid-year 2011. The biomass conversion technology of Fig.1 received a Biomass R&D grant of $1,000,000 from the USDA in 2007, a DOE grant of $1,200,000 in 2010, $400,000 in state funding (Illinois), and is the subject of an additional $2,000,000 DOE grant to develop a microturbine capable of producing electricity from the syngas.

Commercial space development suffers from slow payback and uncertain markets. These factors are unattractive to investors. Renewable energy projects, previously hindered by the hype associated with food-based fuels, are poised for rapid growth for conversion systems which use non-edible biomass, such as the technology in Fig. 1. This paper explores a means by which terrestrial applications can be bootstrapped into a going concern without investor funds. That enterprise, and its technology, is then leveraged for space applications in a staggered-parallel fashion. In this manner, the maturity and risk for space technology can be systematically reduced to the point where the return on investment is early enough, and large enough, to attract the significant capital required.

II. Methods

A. Recycling

Long-duration, remote settlement of space will require a near-perfect environmental controlled life support system (ECLSS). If astronaut safety is first priority, then reprocessing their waste should be priority number 2. Organic waste streams, including fecal matter, food waste, and non-halogenated plastics, contain the carbon, oxygen, and hydrogen essential to life. Figure 3 shows a universal schema for recycling the bi-products of a habitat for humans. This model features a first, primary conversion generating useful products and generating a second waste stream. The second waste stream is further converted to additional products, leaving a minuscule residue suitable as soil. This schema applies equally well to an ECLSS as it does to operations on a farm. The goal is to develop recycling technologies in such a way that they can be applied to either space or terrestrial applications with a minimum of modification.

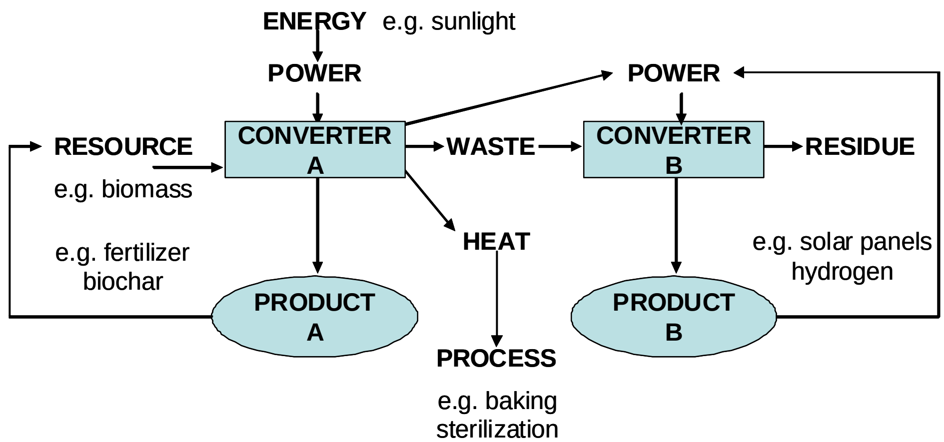

Figure 3. Two-cycle waste conversion schema.

B. Dual-Use

Increasingly humans are learning the degree to which our wastes contaminate the earth's biosphere for everyone. Acid rain in New England from burning coal in Appalachia led to increased use of exhaust scrubbers in the US. The same problem between Japan and China still exists. Radioactive iodine-131 from the Japan reactor meltdown was detected weeks later in South Carolina. Additives to gasoline show up in drinking water. The pesticide DDT is still found in mother's milk two generations after this chemical was banned in the US (although still widely used elsewhere). The implication is clear – we all live downstream of ourselves. As this knowledge becomes part of our cultural mind-set, we will increasingly look for ways to extract value from what is currently called a "waste stream."

Figure 4 shows an application of the schema of Fig. 3 to waste conversion for both terrestrial and lunar applications. Two phases of a lunar settlement are shown, illustrating how this concept can apply at multiple levels of application, providing a wide range of useful products and goods.

	EARTH	MOON	MOON II
RESOURCE	BIOMASS	REGOLITH	WATER
CONVERT A	GASIFIER	DUST ROASTER	SOIL
PRODUCT A	POWER	OXYGEN	LIGHTS
WASTE	ASH/BIOCHAR	MINERALS	BIOMASS
CONVERT B	AIR COOKER	SEPARATOR	GREENHOUSE
PRODUCT B	FERTILIZER	Si, Al, Fe	HABITAT
RESIDUE	MINERALS	REFRACTORIES	CARBON
FINISHED GOOD	ETHANOL	BRICKS	HABITATS
FINISHED GOOD	PV SILICON	SOLAR CELLS	SPS LOX @ GEO

Figure 4. Dual-use applications – terrestrial and space (two-step lunar settlement).

C. Bootstrap

Picking one's self up by one's bootstraps is the metaphor for starting a business without the need for external investment. A unique combination of federal programs, available for a limited time, opens the possibility for bootstrapping of a farm-scale renewable energy system. Figure 5 shows a time line of the start-up, which begins when a customer signs a lease and delivers a down payment equal to the bill of material (BOM) costs to build the first system. This sum is paid to cooperating suppliers who build the components. The few company personnel install and turn on the system, at which time the company becomes eligible for Section 1603 rebate in lieu of tax credits from the US Department of Commerce. This 30% return, paid within 30 days of system start, pays for the supplier labor and margin. The start of lease payments provides on-going revenue to pay expenses and salaries for employees of the burgeoning company. The full-scale, functioning prototype of Fig. 1 is a tangible asset needed as collateral to secure funds from the US Department of Agriculture 9007 loan guarantee program. This offer is only valid in rural areas (50 miles from any metropolis), and requires a willing bank. With such funds, the company can truly begin operations, including a sales and distribution force, and sufficient cash to build at least one more system in advance of a paying customer, or useful as a demo unit at trade shows. With a solvent balance sheet and a steady flow of revenue, this small operation becomes attractive to so-called "mezzanine level" investors interested to fund a going concern to expand operations, carrying the company to a higher level of productivity.

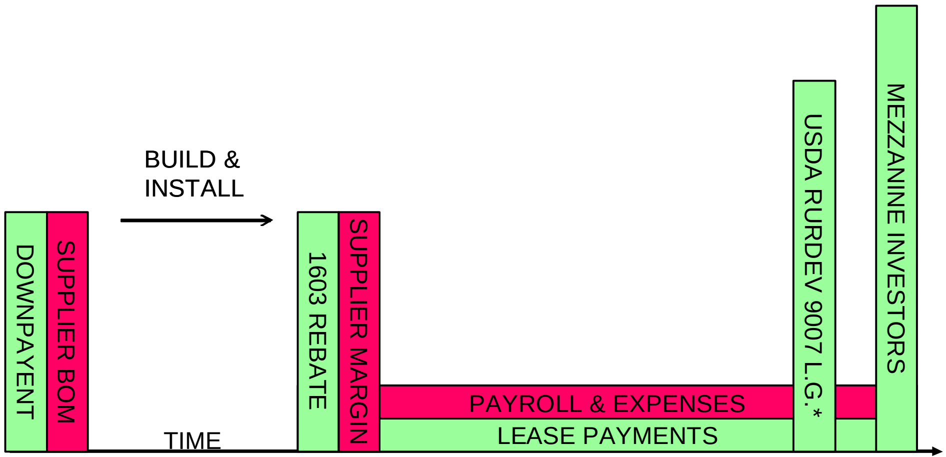

Figure 5. Method and timing to bootstrap biomass renewable energy production.

D. Leveraging ISRU

The system of Fig. 1 is a combined heat and power (CHP) system which produces a net-positive energy output, and a mineral ash rich in micronutrients. Adjusting the performance with pre-programmed recipes, a user can produce biochar, a highly porous pure carbon residue of cell walls that, when used as soil augmentation, enhances food yield[5]. Plants grown in terra preta, the name given to this millennium-old method of increasing yields, thrive from increased moisture retention, and nitrogen adsorption. Biochar is not biologically active, and will not decompose, making it one of the only proven methods of sequestering atmospheric carbon[6].

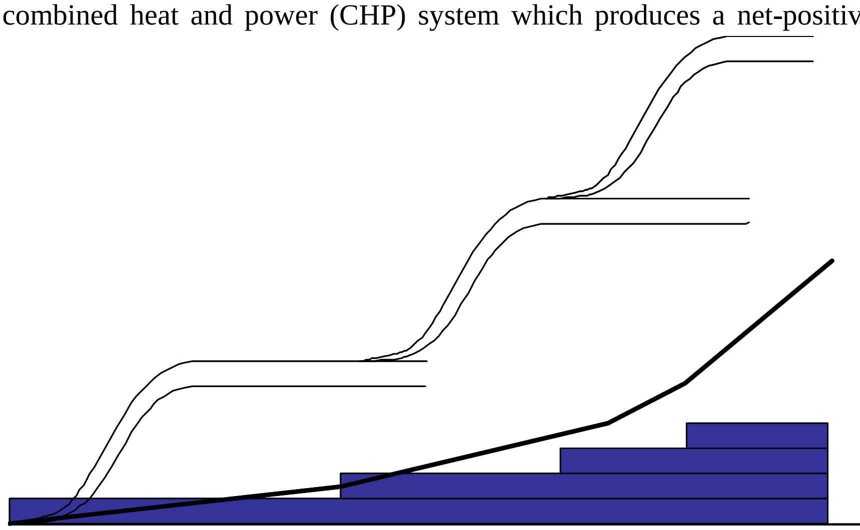

Figure 6. Step-wise introduction of new functions to a platform

Figure 6 shows the step-wise growth of biomass technologies, with each plateau representing the introduction of a new output module to the basic CHP platform. For instance, a slip stream of the syngas can be fed to microorganisms (e.g. *clostridium ljungdahllii*) that convert the gas into ethanol. This valuable liquid can serve as a fuel (for car motors or for rocket engines), and it can be consumed as a libation. A second example is a module to separate and store part of the hydrogen[7] from the syngas for use in fuel cell-powered vehicles or electronics. A third is extracting solar-grade silicon from the mineral ash to form solar cells[8]. By growing in this way, the biomass company builds an ever-increasing revenue stream, capable of supporting research and development on ways to extend these recycling technologies to space applications.

E. Building a NewSpace Company

Figure 7 shows a timeline for taking the step from the ground, up. As the biomass technology grows and expands, profits allow for an increased amount of R&D funding for space applications. An important feature of having bootstrapped the terrestrial company is retention of sufficient control to keep the space vision alive.

The nearest and most obvious opportunity is the International Space Station (ISS). Presently, the ISS ECLSS has a number of effluent streams which are discarded as waste. These include hydrogen from water electrolysis, methane and carbon dioxide from various CO_2 removal systems, plus solid waste which is either returned to earth on the Space Transportation System (a.k.a. Space Shuttle), or burned up in the atmosphere within an unmanned Russian Progress vehicle. Thermochemical conversion of these gaseous and solid waste streams can be performed in a manner similar to biomass conversion, since the chemical elements are the same. Any of the functions or outputs developed for terrestrial use can also be developed for use in space. By closing the ECLSS, resupply can be greatly diminished, enabling longer duration stays at nearly self-sufficient settlements on the moon, at an asteroid, on Mars, or in orbit.

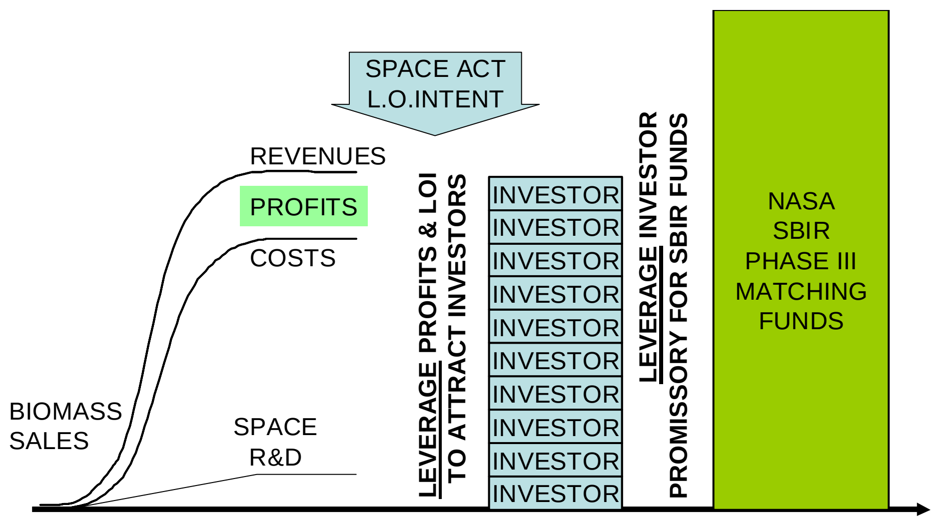

Figure 7. Bootstrap ISRU to ISS waste processing.

Taking the leap from ground to orbit with a NewSpace company takes careful planning. First, there must be a recognized customer willing to pay for a functioning system. In the U.S., this is done through a Space Act[9] Agreement, which NASA uses to execute contracts, leases, or cooperative agreements with other organizations, including private industry. The goal of the space R&D shown in Fig. 7 is to provide sufficient data, costs, and systems integration information to provide those within NASA responsible for the ISS reasonable assurance of the potential to fly a safe, working system. The signed lease becomes the collateral needed by investors to provide a guarantee that, should all the engineering be done properly, they can realize a return on their investment. It is expected that this level of private investment will be sufficient to build, test, and package the system, but perhaps not enough to launch.

There are two means within the US space program by which a launch can be provided to a NewSpace company. In 2007, the Congress designated the ISS as a National Lab. As part of this program, the Space Act Agreement can include a pre-paid ride to Station for the hardware, and an intent to use astronaut labor to install and operate the system. The other means is through cost match within the SBIR program. Contractual language does not limit NASA on the ratio of public to private funds, so it is conceivable that NASA may contribute sufficient funds to pay for a private flight to the ISS. Perhaps the earliest of several possibilities in this arena is the DragonLab being developed by the company Space Exploration Technologies. This re-used crew capsule may be used to deliver supplies and equipment to ISS with a relatively modest specific launch cost.

III. Results

The design of an ISS thermochemical conversion system can be developed based on data generated in the terrestrial biomass system. It is important to understand that the ideal stoichiometry for creating useful syngas creation is to have hydrogen, carbon, and oxygen in a ratio of 2:1:1, thereby producing equal molar quantities of hydrogen (H_2) and carbon monoxide (CO) gases. Plastics and methane are oxygen deficient, but when combined with fecal matter and food residue, the mix can be brought close to the ideal ratio.

Estimates indicate that a system massing 115 kilograms, with a volume of 1.2 by 0.75 by 0.5 meters, and requiring 1.3 kilowatts of power can produce two moles of syngas each orbit. Ideal mixtures will be completely converted to gas, while mixtures deficient in oxygen will leave behind a carbon residue – biochar, useful for growing plants.

IV. Discussion

The ISS ECLSS closing system described above produces a syngas output which is not in the form needed by the present state of the Station. As with the terrestrial unit, from this syngas, astronauts can make electricity or heat (both requiring oxygen, but producing water, which can be easily recycled), ethanol, fertilizer, and soil augmentation. The importance of providing these products is in demonstrating the ability to close the ECLSS loop. It is only with this confidence that we can economically populate long duration settlements in the spaces beyond low earth orbit.

This paper has described one method by which a NewSpace company can be created and funded through dual-use of newly-invented technologies. The author is eager for advice, suggestions, and investment to help turn this plan into reality. The long term benefits to the US space program, and to mankind in general, are considerable.

V. Acknowledgements

This work was supported in part by NASA SBIR grant number NNX09CB52C.

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