HYDROGEN PLASMA REDUCTION OF PLANETARY MATERIALS. R. Currier, J. Blacic, and M. Trkula, MailStop J-567, Los Alamos National Laboratory, Los Alamos NM 87545, USA (currier@lanl.gov, jblacic@lanl.gov, mtrkula@lanl.gov)

Large-scale utilization of resources in space exploration and colonization must include the ability to provide oxygen for propulsion and life support. In addition, metals and other structural materials must be produced from locally available planetary resources. We propose to develop a new extractive process for resource utilization in space. This process also has the potential for water extraction from hydrous minerals (water could in turn be used to produce oxygen). Reduction of anhydrous silicate and oxide minerals to produce oxygen and metals will require the importation of hydrogen, which must be recycled with minimal losses. The proposed process uses a microwave or radio frequency produced atomic hydrogen plasma. Electromagnetic energy couples to hydrogen gas to form a non-equilibrium plasma in a reactor configuration that we believe is ideal for low gravity applications. One can form a plasma with high concentrations of atomic hydrogen, at modest bulk temperatures. Thus, we force the system into a standard state where the reductant atomic hydrogen is the key species. This dramatically shifts standard free energies of reaction, for example:

Reaction	ΔG (H_2-based)	ΔG (H-based)
$TiO_2 + (2H_2 \text{ or } 4H) \rightarrow Ti + 2H_2O$	+104 kcal	-91 kcal
$Al_2O_3 + (3H_2 \text{ or } 6H) \rightarrow Al + 3H_2O$	+224 kcal	-81 kcal
$TiF_3 + (3/2\ H_2 \text{ or } 3H) \rightarrow Ti + 3HF$	+129 kcal	-18 kcal

Shifting the chemistry from molecular hydrogen to the atomic analogs clearly shifts the equilibrium from one favoring reactants to one favoring products. A conceptual flow sheet for a space-based process using this chemistry might appear as shown in Figure 1:

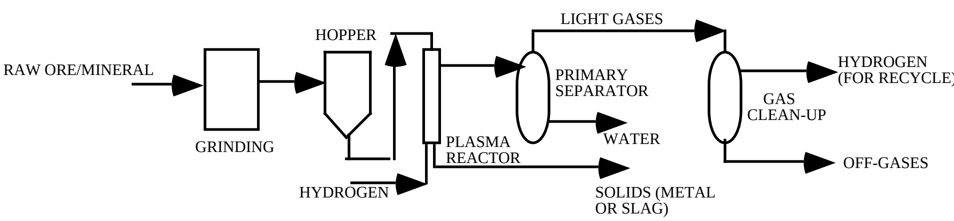

Figure 1. Process flow sheet. When produced as a product stream, the water could then be split to yield oxygen and hydrogen for recycle.

Central to this process is the use of fluidized bed plasma reactors, which permit solid particles to be transported through the glow discharge. We are currently studying hydrogen extraction chemistry in several fluidized bed configurations. Initial screening experiments are being conducted in well-agitated fluidized beds with the plasma maintained above. Gas flow is selected so that particles are constantly carried into the plasma region. We are also examining circulating plasma fluidized bed reactors. Here, solid particles are fed from a conventional fluidized bed (the reservoir) into a "riser" section in which they are transported by high velocity gas through the plasma region. At the exit of the riser, the gas is separated from the solids (e.g. in a cyclone) and the solids fall back into the reservoir bed, where they can be fed through the riser section again. By varying the gas flow velocity in the riser section and pressure differential between the reservoir and riser, one can vary the solids number density in the riser for optimal electromagnetic coupling. For space-based applications, we propose a related process in which the mineral particles are fed from a reservoir fluidized bed or hopper into a "downer" reactor where they simply fall under reduced gravity through the glow discharge region as indicated in Figure 2:

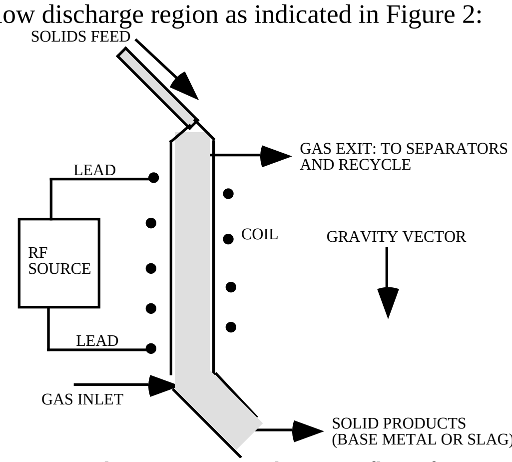

Figure 2. A downer reactor with counter flow of gas. While an inductively coupled plasma configuration is shown here, other means of plasma generation (e.g. with microwave energy) are also possible.

Upon separation from the gas stream at the exit of the downer section, feed particles could be transported back to the reservoir for another pass if needed, or simply disposed of. The unreacted hydrogen gas would be recycled after separation from other products. Similarly, upon splitting of water products to produce oxygen, the hydrogen gas would be recycled. The downer reactor offers several advantages which enhance the probability of success. First, by controlling the solids feed rate from the reservoir and the gas flow in the downer section, we could achieve essentially a counter-current reactor with continuous removal of volatile byproducts from the plasma region. This maintains the driving force towards metal production and would help limit back reactions. Second, the downer reactor allows the solids to fall essentially in plug flow (i.e. a delta function residence time). This permits precise control over the extent of reaction. A downer plasma reactor could also be configured with continuous addition and removal of solids. Good gas-solid contact maximizes the desired reactions with atomic hydrogen and aids in uniform conversion of reactants to products. Of course, our demonstration experiments involving reduction of mineral surrogates to the base metals and water extraction from minerals must ultimately be correlated to the corresponding operations in low gravity. We will discuss an integrated approach to process development involving demonstration experiments and initial results and concurrent engineering. In particular, we will discuss key issues related to electromagnetic coupling in particle-laden gas streams, the chemical kinetics of metal extraction, plasma-solid interactions, and chemical process design. The importance of the last issue should not be underestimated since an integrated set of unit operations will be necessary. We believe future assessments must continue to include: composition dependencies, temperature and flow requirements for feed and make-up streams, acceptable particle number densities and size distributions, separations in low gravity, and the overall process power requirements.