CARBON MONOXIDE SILICATE REDUCTION SYSTEM. Mark Berggren, Robert Zubrin, Stacy Carrera, Heather Rose, and Scott Muscatello, Pioneer Astronautics, 11111 W. 8th Ave., Unit A, Lakewood, CO 80215, mberggren@pioneerastro.com

Introduction: The Carbon Monoxide Silicate Reduction System (COSRS) is a novel technology for recovering large amounts of oxygen from lunar soils. Soils are sequentially subjected to iron oxide reduction by carbon monoxide, in-situ deposition of carbon throughout the soil by carbon monoxide disproportionation catalyzed by metallic iron, and finally high-temperature reduction of silicates by the deposited carbon. Figure 1 shows the process schematic.

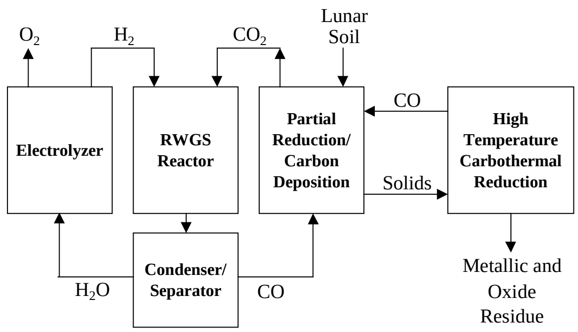

Figure 1: COSRS process schematic.

Approximately 2 kilograms of oxygen per 100 kilograms of soil are recovered by the initial iron oxide reduction step. Up to an additional 28 kilograms of oxygen per 100 kilograms of feed soil are recovered during the carbothermal reduction step. Process gases are fed to a Reverse Water Gas Shift (RWGS) unit for regeneration of carbon monoxide and recovery of oxygen by electrolysis from the resulting water. The COSRS-RWGS-electrolysis is a closed system with only small losses of carbon to the spent soil. The metallic and oxide slag residues have value for in-situ resource utilization.

A six-month, NASA SBIR Phase I COSRS program was conducted in 2005. Each unit operation was separately demonstrated in the laboratory using both JSC-1 lunar and JSC Mars-1 soil simulants. A final integrated, closed-loop, COSRS-RWGS-electrolysis experiment produced oxygen from JSC-1 lunar soil simulant.

Program Accomplishments: Thermodynamic evaluations led to selection of a substoichiometric carbon:silicon dioxide ratio to minimize carbon losses to the carbothermal reduction residue. Under conditions selected for Phase I demonstration, about 15 kilograms of oxygen per 100 kilograms of soil were recovered from both lunar and Mars soil simulants using the COSRS process at temperatures up to 1,600°C. Process leverage (mass of oxygen recovered divided by mass of carbon lost to the residue) on the order of 25 was achieved in each case. COSRS was successfully integrated with an RWGS-electrolysis system during iron oxide reduction of lunar soil simulant. The integrated system produced the desired solids product and demonstrated that minor gas constituents stabilize at very low concentrations after extended periods in the closed RWGS loop.

Carbothermal reduction residues contained spheres of iron and silicon metal above a glassy oxide matrix. Figure 2 shows the metallic and oxide phases in JSC-1 carbothermal reduction residue. Electron microprobe analysis of the residue confirmed distinct separation of the metal and oxide phases, opening the possibility of byproduct separation and recovery.

Figure 2: JSC-1 carbothermal reduction residue.

The Phase I results demonstrated oxygen recoveries of five times that possible using hydrogen as a reductant. Up to ten times more oxygen than could be recovered by hydrogen reduction is possible by increasing the mass of carbon deposited before carbothermal reduction. Further trade studies are needed to optimize the carbon:silicate ratio with respect to oxygen recovery and leverage.

Acknowledgement: This work was conducted under NASA Small Business Innovation Research (SBIR) funding. Kris Lee was the NASA JSC Contracting Officer's Technical Representative (COTR).