REDUCTION OF SIMULATED LUNAR GLASS BY CARBON AND HYDROGEN AND ITS IMPLICATIONS FOR LUNAR BASE OXYGEN PRODUCTION; D. S. McKay[1], R. V. Morris[1], and A. J. Jurewicz[2]. [1]NASA Johnson Space Center, Houston TX 77058; [2]LESC, Houston TX 77058.

INTRODUCTION. Oxygen production will be a major goal during the early years at any lunar outpost or base. This oxygen will be used mainly for life support and for propellant to enable the lunar lander vehicle to go from the lunar surface to lunar orbit and return.

Over twenty different processes have been proposed for extracting oxygen from lunar materials [1]. All include reduction of lunar rocks and soils and capture of the liberated oxygen and/or water. A few of these have had significant laboratory work performed to validate their feasibility. Among the most studied processes is the reduction of ilmenite by hydrogen to form metallic iron, titanium oxide, and water [2,3,4]. The water obtained from the reactor is electrolyzed to produce oxygen and hydrogen, which can be recycled. The processing would take place in a fluidized bed reactor at subsolidus temperatures. If the reduction process is not efficient for other ferrous-bearing materials, it may be necessary that the ilmenite be concentrated prior to reduction by beneficiation, a process which is likely to be complex and inefficient (particularly for mature lunar soils) because of the relatively low content of identifiable ilmenite grains [5].

We examine here the reduction of ferrous iron in simulated lunar glass by either carbon, CO/CO_2 mixtures, or hydrogen. Glass is ubiquitous on the Moon and extremely abundant at some sites (lunar pyroclastic areas) so that little or no beneficiation may be necessary. The mining requirements are also greatly reduced at sites where glass is a major phase.

EXPERIMENTAL. We have performed preliminary experiments in which we exposed a lunar composition synthetic glass to reducing conditions at temperatures near the liquidus (1200°C) or below the solidus (<1000°C) for the material. Initial glass composition (Table 1) is approximately Apollo 11 soil composition. Reducing conditions were obtained (1) by sealing samples plus elemental carbon in graphite capsules within evacuated silica tubes, and (2) by using CO/CO_2 or H_2 in a controlled atmosphere furnace at near atmospheric pressure (Table 2). The resulting solids were analyzed with Mossbauer spectroscopy to determine the iron-bearing phases present and the relative proportions of iron associated with those phases.

RESULTS AND DISCUSSION. Maximum reduction of ferrous to metallic iron occurred for the sample (A11-AJ05) reduced with hydrogen (Table 2 and Figure 1). From the Mossbauer spectrum, 53% of the area results from Fe^0, and 41% and 6% from ferrous iron in pyroxene and ilmenite, respectively. This result implies that hydrogen reduction may be a viable process for producing oxygen from lunar glass. The mechanisms and kinetics of this process are not known. However, the reaction occurs at subsolidus temperatures, so that it does not involve direct reduction of a melt. As the remainder of the iron is in the crystalline phases ilmenite and pyroxene, it is not yet clear whether Fe^0 is produced directly from the glass, or whether it is produced sequentially from the ilmenite and pyroxene which formed by devitrification of the glass. For the two samples which do not have Fe^0 (A11-AJ03 and -AJ04), the pyroxene/ilmenite ratio is about 3.4 to 1, which is significantly lower than the 6.8 value for A11-AJ05. This suggests either that some of the ilmenite was reduced after devitrification, or that relatively less ilmenite was formed because the glass was depleted in iron by prior crystallization of metallic iron.

Reduction of iron to a metal also occurred in experiments using elemental carbon as the reducing agent. For the 1000°C experiment (A11-AJ02), metallic iron did form, but its relative proportion was much less than for the H_2-reduction experiment (10 versus 53%). For the 1200°C experiment (A11-AJ01), in which the sample partially melted, cementite (Fe_3C) formed. Production of cementite would be detrimental to the application of the process because it would tie up carbon and prevent easy recycling of this reducing agent. While additional steps might be developed to decompose the cementite and recover carbon, this would add to the complexity of the process and likely increase the mass and cost of the required systems significantly.

In summary, subsolidus reduction of lunar composition glass with hydrogen has been demonstrated to be a viable process and should be considered for further development. The reaction mechanisms and kinetics have yet to be determined. If this process behaves similarly with Apollo 17 orange glass composition (Table 1), and were 50% efficient at reducing the iron, it would produce 24.5 kg of oxygen for each ton of glass mined and processed. For comparison, a similar amount of unbeneficiated high titanium lunar soil contains about 2% free ilmenite grains [5] which, if beneficiated and extracted with hydrogen at 100% efficiency, would yield about 2 kg of oxygen per ton of mined soil. If all of the ilmenite were concentrated by beneficiation, the yield would go up to about 100 kg per ton of processed ilmenite; however, 50 tons of soil would have to be mined to provide the ilmenite. It seems clear that the reduction of lunar glass may have some advantages over the reduction of lunar ilmenite and should be studied in greater detail.

REFERENCES: [1] Register and McKay, *Proc. 2nd Workshop on in situ Res. Util.*, in press; [2] Gibson and Knudsen, *Integ. Lunar Mat. Manuf. Process*, U.S. patent 4,948,477; [3] Gibson and Knudsen, *Lunar Bases and Space Activities of the 21st Century,* 1985; [4] Briggs and Sacco, *Hydrogen Reduction Mechanisms of Ilmenite between 823-1353 K*, Rept. to Adv. Proj. Res. Off., NASA-JSC, 1990; [5] Heiken and Vaniman, *P20LPSC*, 239, 1990; [6] Morris *et al.*, *Handbook of Lunar Soils*, PMB Pub. 67, 1983.

Figure 1. Mossbauer Spectra

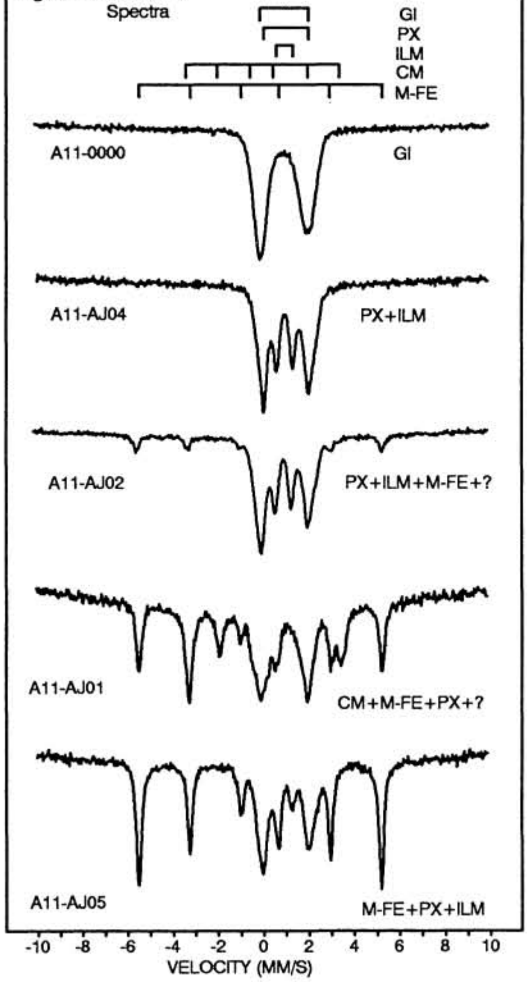

Table 1. Composition of starting material and comparison lunar materials. Lunar compositions from [6].

	Synthetic Glass	Apollo 11 Soil 10084	Apollo 17 Orange Glass
SiO_2	44.65	41.0	38.57
TiO_2	6.59	7.3	8.81
Al_2O_3	13.42	12.8	6.32
Cr_2O_3	0.14	0.31	0.75
Fe_2O_3	0.00	0.0	0.0
FeO	13.95	16.2	22.04
MnO	0.14	0.22	0.30
MgO	7.38	9.2	14.44
CaO	12.25	12.4	7.68
Na_2O	0.50	0.38	0.36
K_2O	0.02	0.15	0.09
P_2O_5	0.02	0.04	
Total	99.06	99.96	99.40

Table 2. Experimental conditions and Mossbauer results. Phases present are glass (Gl) pyroxene (Px), ilmenite (Ilm), cementite (Cm), metallic iron (M-Fe), and an unidentified phase (?). Mossbauer parameters are isomer shift (IS), quadrupole splitting (QS), hyperfine splitting (B), and relative peak area (A) of iron associated with each phase.

Sample	$\log(PO_2)$	T C	t hr	Phase	IS mm/s	QS mm/s	B T	A %
A11-0000	A11 Syn. Glass			Gl	1.07	2.07		100
A11-AJ01	-18 (C-Sat.)	1200	3	Px	1.10	1.71		29
				?	-0.08			8
				Cm	0.19	0.00	20.6	32
				M-Fe	0.00	-0.01	33.1	31
A11-AJ02	-18.2 (C-Sat.)	1000	66	Ilm	1.06	0.66		18
				Px	1.16			61
				?	-0.10	0.00		10
				M-Fe	0.00	-0.01	33.1	11
A11-AJ03	-16.7 (CO,CO_2)	950	180	Ilm	1.07	0.69		21
				Px	1.15	2.08		79
A11-AJ04	-15.8 (CO,CO_2)	1000	120	Ilm	1.07	0.70		25
				Px	1.14	2.04		75
A11-AJ05	-21 (H_2)	1000	24	Ilm	1.05	0.69		6
				Px	1.12	2.07		41
				M-Fe	0.00	0.00	33.2	53