

## EXTRACTION OF OXYGEN FROM THE MARTIAN ATMOSPHERE

C. England

<sup>1</sup>Jet Propulsion Laboratory, Pasadena, CA 91109, cengland@jpl.nasa.gov

A mechanical process was designed for direct extraction of molecular oxygen from the martian atmosphere based on liquefaction of the majority component, CO<sub>2</sub>, followed by separation of the lower-boiling components. The atmospheric gases are compressed from about 0.007 bar to 13 bar and then cooled to liquefy most of the CO<sub>2</sub>. The uncondensed gases are further compressed to 30 bar or more, and then cooled again to recover water as ice and to remove much of the remaining CO<sub>2</sub>. The final gaseous products consisting mostly of nitrogen, oxygen, and carbon monoxide are liquefied and purified by cryogenic distillation. The liquefied CO<sub>2</sub> is expanded back to the low-pressure atmosphere with the addition of heat to recover a majority of the compression energy and to produce the needed mechanical work. Energy for the process is needed primarily as heat to drive the CO<sub>2</sub>-based expansion power system. When properly configured, the extraction process can be a net producer of electricity.

The conceptual design, termed "MARRS" for *Mars Atmosphere Resource Recovery System*, was based on the NASA/JSC Mars Reference Mission (MRM) requirement for oxygen. This mission requires both liquid oxygen for propellant, and gaseous oxygen as a component of air for the mission crew. With single redundancy both for propellant and crew air, the oxygen requirement for the MRM is estimated at 5.8 kg/hr. The process thermal power needed is about 120 kW, which can be provided at 300-500°C. A lower-cost nuclear reactor made largely of stainless steel could serve as the heat source.

The chief development needed for MARRS is an efficient atmospheric compression technology, all other steps being derived from conventional chemical engineering separations. The conceptual design describes an exceptionally low-mass compression system that can be made from ultra-lightweight and deployable structures. This system adapts to the rapidly changing martian environment to supply the atmospheric resource to MARRS at constant conditions.

The large amounts of liquid CO<sub>2</sub> by-product that are produced enable a comprehensive martian surface architecture using this liquid as an open cycle working fluid. While most of the 1000 kg/kg oxygen is expanded for power recovery, a small fraction is stored and made available for emergency or backup power, transportation, and surface operations such as drilling. The availability of highly redundant backup power and transportation systems makes the MARRS concept particularly attractive for piloted missions to Mars.

The current study outlines an inherently flexible surface architecture for Mars exploration that uses nuclear heat, a compression-dominated process for extraction of atmospheric resources, and provides a mechanism for highly redundant and reliable operations. The amounts of minor components in the atmosphere, however, are uncertain. While the conceptual design for MARRS is based on a 0.13% oxygen concentration, the actual average value is now believed to be about 0.3%. Such a high value would allow even greater flexibility in design, and greatly reduce the energy and mass requirements to produce oxygen for the MRM. A more detailed design is needed to account for the uniquely high variability in composition, pressure and temperature that characterize the martian atmospheric environment.