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# CO<sub>2</sub> ACQUISITION MEMBRANE (CAM) PROJECT

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## OBJECTIVE

The CO<sub>2</sub> Acquisition Membrane (CAM) project will develop, test, and analyze membrane materials for separation and purification of carbon dioxide (CO<sub>2</sub>) from mixtures of gases, such as those found in the Martian atmosphere. The CAM technology will enable passive separation of these gases, allow energy efficient acquisition and purification of these important resources, and lay the foundation for future unmanned sample return and human space missions. The CAM membranes are targeted toward *In Situ Resource Utilization* (ISRU) applications, such as *In Situ Propellant Production* (ISPP) and *In Situ Consumables Production* (ISCP).

### I. Planned Activities

CAM is a ground-based project that is cooperative among three institutions: Lockheed Martin (LM), the Colorado School of Mines (CSM), and Marshall Space Flight Center (MSFC). Each of these institutions plays an important role in the development of these new materials. CSM will design, model, and fabricate a series of membranes; LM will test the membranes to measure the gas separation performance under simulated Mars and other conditions, and MSFC will perform materials characterization analyses to determine lattice parameters and dimensional structures.

In microporous materials, such as zeolite and carbon molecular sieves, the pore size approaches the size of the molecules being separated. Due to the close proximity of the pore wall, non-bond interactions between the penetrant molecule and the pore wall become important. Under these conditions, very selective separations can be attained from interactions among several different transport mechanisms, including surface diffusion and size discrimination. Both of these mechanisms may be utilized in the separation of CO<sub>2</sub> from N<sub>2</sub> for ISRU applications on Mars. Since CO<sub>2</sub> is both smaller (kinetic diameter of 0.33 nm) and more strongly adsorbing than the larger N<sub>2</sub> molecule (0.364 nm), a microporous inorganic membrane is ideal for the separation of CO<sub>2</sub>. Additionally, zeolite membranes may be used to separate molecules by molecular size using a molecular sieve-like mechanism. Zeolites are aluminosilicates with a well-defined, crystalline structure. The pore openings in the crystal are on the order of molecular dimensions (typically 3 to 7 Å), a size through which small molecules may pass, but bulky or high molecular weight molecules will not. For over thirty years researchers have been attempting to develop crack free zeolite membranes, and the scientific literature lists very few successful fabrication and test activities.

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Recently, however, several researchers have independently formed defect-free zeolite membranes. For example, ongoing projects at CSM have formed selective silicalite films on porous stainless steel supports. Using this technology and other methods, a variety of candidate membranes will be identified, designed, modeled, and fabricated for the CAM project.

Once the candidate membrane types have been identified and fabricated, experiments will be conducted to characterize the separation performance under simulated Martian conditions using the Membrane Test Facility (MTF) at LM. The MTF is designed to produce a wide range of temperature and pressure conditions, and control the gas composition to simulate the Mars atmosphere. A membrane characterization experiment will consist of sealing the membrane sample in place within the MTF, and subjecting the sample to a wide range of conditions while measuring the trans-membrane pressure, gas flow rate, and composition of gas that passes through the membrane. In addition to performance tests, the thin-film membrane samples will also be analyzed using a variety of materials characterization techniques that are available through the Microgravity Science and Applications Department (MSAD) of NASA/MSFC. The analyses will include: (1) x-ray microscopy to view sequential steps in the fabrication process at various temperatures, allowing the crystalline pore size distribution to be determined as a function of temperature, (2) microprobe analyzer for quantitative analysis of the elemental composition, (3) x-ray diffraction analysis to determine lattice dimensions and measure surface variability, and (4) scanning electron microscopy to image the grains present in the thin film, and measure the size, orientation, distribution, and morphology of the crystals.

The data from these experiments and characterization activities will be analyzed to determine how well the membranes separate CO<sub>2</sub> from other atmospheric gases, define the conditions for optimal separation, and elucidate the relative merits of heating the membrane or compressing Mars atmosphere prior to separation. Additionally, the materials characterization results will be correlated with measured separation performance to reconcile the data, establish the relative contribution of different transport mechanisms, and optimize fabrication variables.

## **II. Requirement for Microgravity**

There is no requirement for microgravity. The CO<sub>2</sub> Acquisition Membrane project is a ground-based program geared toward development of materials for use with ISRU systems.

## **III. Significant Results**

The development of thin-film membrane materials for passive separation of CO<sub>2</sub> from other gases will have significant impact on the design and implementation of ISRU systems that utilize CO<sub>2</sub> on Mars. In addition, the results from the CAM activities will allow factors to be determined to scale ISRU processes for use in various Mars missions and scenarios. The gas separation is essentially passive, requiring only that atmosphere gases pass through the membrane to either purify CO<sub>2</sub> for ISRU processes, or nitrogen and argon buffer gases for ISCP applications. Alternative techniques to separate buffer gases primarily use bulk adsorption to selectively bind CO<sub>2</sub>. While these processes have shown successful operation, the large mass of the sorbent bed, many times the mass of the separated gas, restricts the applicability. These systems require large swings in thermal energy to cycle the temperature, significant power, and the use of large, massive radiators. The simplicity of a passive thin film to perform the same function with no power is quite attractive.