NUCLEAR-POWERED CO-ELECTROLYSIS FOR MARS COMBINED LIFE SUPPORT AND METHANOL PRODUCTION C. Stoots[1], R. O'Brien[1], and M. McKellar[1], [1]Idaho National Laboratory, 2525 Fremont Ave., Idaho Falls, ID 83415, carl.stoots@inl.gov.

Introduction: The Idaho National Laboratory has been researching the use of high temperature solid-oxide fuel cell technology to reduce H_2O and CO_2 simultaneously (co-electrolysis) to produce syngas (H_2 and CO), the raw material for synthetic methane, methanol, and other liquid hydrocarbons. NASA has become interested in the co-electrolysis technology since CO_2 acquisition and utilization technologies are crucial for sustainable life support and in-situ fuel production for Mars exploration. In response, the Idaho National Laboratory has begun studying the feasibility of high temperature co-electrolysis in an integrated nuclear-powered concept for combined life support and in-situ resource utilization for space applications.

Discussion: Some of the energy-related requirements for a manned mission to Mars include: a space propulsion technology; in-situ generation of the return trip propellant; sustainable life support systems; electrical generation for instrumentation, communications, etc.; and generation of high energy density fuels for Mars surface operations (e.g., long range mobility). Nuclear thermal propulsion (NTP) has been identified as a key enabling technology for manned and robotic missions to Mars. NTP heats a working fluid, usually hydrogen, to a high temperature and then expands it through a rocket nozzle to create thrust. The higher energy density of nuclear fuel over chemical fuels results in increased propellant efficiency and lower overall lift-off mass. In spite of the advantages of NTP, it is still inefficient and too costly to transport enough propellant (e.g., hydrogen) to Mars for the return flight. Similarly, it is too costly to transport high-density fuels for Mars surface operations. Thus, In-Situ Resource Utilization (ISRU) for production of return propellant and fuels is a key enabling technology for a round trip Mars mission.

For the return propellant, either hydrogen produced from Mars water deposits or CO_2 derived from the Mars atmosphere could be captured and stored. Methanol is a leading fuel candidate for surface operations. Methanol's low freezing temperature (175 K) and vapor pressure allows it to be stored unheated or pressurized under typical Mars temperature conditions. With oxygen, methanol can then be used in internal combustion engines and fuel cells for surface power / electrical generation. Methanol can be synthesized relatively easily from Mars atmospheric CO_2 and H_2, the only problem being to assure adequate quantities of H_2. Capture and recycle of water in the life support system will be important. Therefore, the in-situ

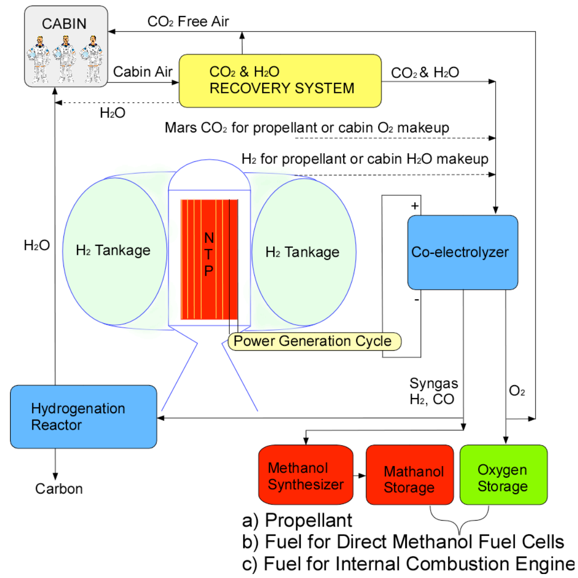

Figure 1. INL concept for an integrated nuclear-powered life support, electrical generation, methanol production, and hydrogen production system.

methanol production process and the life support process need to be integrated systems, with nuclear power as the ultimate energy source.

Fig. 1 represents a concept being studied at the Idaho National Laboratory (INL) for completely integrating closed loop regenerative life support, electrical generation, methanol production, and hydrogen production (with corresponding oxygen production). The feasibility study will assess mass balances, energy efficiency, and power-to-weight ratio for a manned mission to Mars. A key component is the co-electrolyzer.

Fig. 2 depicts the typical closed-loop air revitalization architecture: CO_2 removal and recovery, CO_2 chemical reduction, and oxygen generation through water electrolysis [1]. NASA has considered a number of CO_2 reduction options among which the Sabatier and Bosch processes have gained considerable attention and development. The co-electrolysis technology combines the CO_2 reduction and oxygen generation processes above into a single hardware process and offers a significant mass reduction. The co-electrolyzer is a high temperature solid-oxide fuel cell operated in reverse such that it reduces CO_2 and H_2O simultaneously to produce syngas (CO and H_2) and oxygen. The technology is a combined process that involves steam electrolysis, CO_2 electrolysis, and the reverse water gas shift (RWGS) reaction. The process takes place at around 800°C and is highly efficient. In experimental studies, the INL has demonstrated that

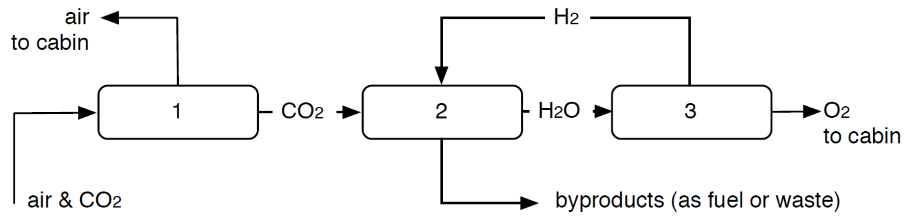

Figure 2. Schematic of a typical closed-loop air revitalization system. (1) CO_2 removal and recovery system, (2) CO_2 chemical reduction system, (3) water electrolysis system [1].

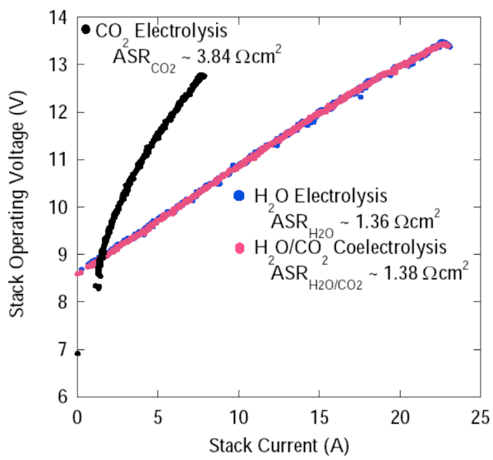

Figure 3. Electrical efficiency as represented by Area Specific Resistance of co-electrolysis versus separate water and pure CO_2 electrolysis [2].

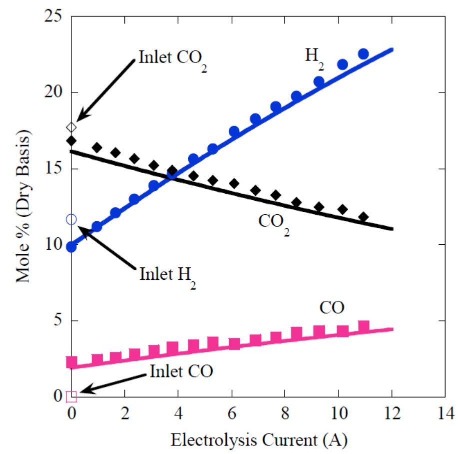

Figure 4. Sample co-electrolysis experimental results (symbols) compared to chemical equilibrium predictions (lines) [3].

high temperature electrolysis is more efficient than conventional low temperature electrolysis and that co-electrolysis is electrically more efficient than separately electrolyzing water and CO_2 (Fig. 3).

Fig. 4 depicts co-electrolysis experimental data obtained at the INL. Open symbols at zero current represent the cold inlet gas composition. Closed symbols at zero current represent the outlet gas composition heated to operating temperature (800ºC) and quenched. The drop in CO_2 and H_2 mole fractions from inlet values is solely due to the RWGS. As the electrolysis current was increased, the yield of syngas increased linearly while the concentration of CO_2 decreased.

The INL has also coupled high temperature electrolysis with a CO_2 separation membrane and methanation reactor to demonstrate integrated synthetic methane production from a feedstock of water and a simulated flue gas containing CO_2 [4]. This demonstration is now being extended to methanol production. Overall, co-electrolysis offers a convenient and thermodynamically advantageous means of converting H_2O and CO_2 to syngas for production of synfuels.

In studies sponsored by NASA Ames Research Center, the INL has found that it is theoretically possible to revitalize the atmosphere of a space cabin and recover oxygen for human metabolic use while simultaneously providing syngas for fuel production [5]. INL will employ INL-developed models and systems analyses to size components and inventories for a hypothetical manned mission to Mars. This will assess the concept's feasibility, energy efficiency, and power-to-weight ratio.

References:

[1] McKellar, M. *et. al.*, "The Concept and Analytical Investigation of CO_2 and Steam Co-Electrolysis for Resource Utilization in Space Exploration", 40th ICES, Barcelona, July 11-15, 2010.

[2] Stoots, C. *et. al.*, "High temperature co-electrolysis of H_2O and CO_2 for syngas production", Fuel Cell Seminar, Honolulu, Nov 13-17, 2006.

[3] Stoots, C., *et. al.*, "High Temperature Coelectrolysis for Direct Syngas Production Using Solid Oxide Cells", European Solid Oxide Fuel Cell Forum, Lucern, Paper A112, 2008.

[4] Stoots, C. *et. al.*, "Integrated Operation of the INL HYTEST System and High-Temperature Steam Electrolysis for Synthetic Natural Gas Production", *Nuclear Technology*, in press.

[5] McKellar, M. *et. al.*, "The Mathematical Analysis of a Novel Approach to Maximize Waste Recovery in a Life Support System", IMECE, Denver, Nov 11-17, 2011.