MARS METHANE: A CRITICAL IN-SITU RESOURCE TO SUPPORT HUMAN EXPLORATION M. Max[1] and S. M. Clifford[2],. [1]Hydrate Energy International, 612 Petit Berdot Drive, Kenner, LA 70065-1126 U.S.A (michaelmax1@mac.com); [2]Lunar and Planetary Institute, 3600 Bay Area Blvd, Houston, TX 77058.

Introduction: From the time of the first spacecraft flyby of Mars in 1965 until the late 1970s, Mars has been characterized as a resource-poor planet whose thin CO2 atmosphere and numerous craters made it seem more closely related to the Moon than the Earth. This early view of Mars was not encouraging for near-term human exploration because all the materials required for a voyage to Mars and establishing a base there would have had to be transported from Earth, including the fuel for the return trip.

More recent spacecraft investigations have dramatically changed this view. Although the surface appears barren, a large amount of water ice is present at both poles as extensive (~1000 km diameter) layered deposits as much as ~3-4 km deep [1,2] There is also geophysical evidence that ice is widespread in the shallow (top meter) subsurface at mid- to high-latitudes [3] and may be present at greater depths elsewhere on the planet [4].

Estimates of the total inventory of water on Mars are based in part on the amount of water required to produce the enormous scours associated with the Martian outflow channels [5]. These erosional depressions – which are tens of kilometers wide, hundreds of kilometers long, and up to 1-2 km deep -- generally emanate full-born from localized regions of collapsed and disrupted terrain. The scale of the braided and streamlined forms found within their beds, combined with the absence of any identifiable tributaries, indicate an origin by catastrophic floods, apparently fed by the catastrophic discharge of subpermafrost groundwater [6,7]. The total inventory of water on Mars has been estimated as equivalent of a global layer ~0.5 to ~1 km deep [5, 8].

The growing evidence for abundant water, combined with the in situ and remote detection of evaporites (such as sulfates, gypsum, carbonate), various salts, metals (Fe, Mg, Ti, Na and Al), and, most recently, large plumes of atmospheric methane [9, 10], have led to a substantial revision of the resource characterization of Mars. These materials are the basic feedstock of the modern chemical engineering industry and could be harvested and utilized to support and expand the human exploration of Mars and beyond [11,12].

Substantial amounts of accessible water is the the most critical material, and Mars has enough. The next most critical material is methane.

Methane in Subsurface Mars: The possibility that an abundant supply of hydrocarbons may be stored in the Martian subsurface is supported by the apparent subsurface origin of the methane recently detected in the Martian atmosphere [9,10,13-15]. Various studies suggest that large quantities of methane may have been produced – either biogenically or abiogenically – within the subsurface. As on Earth, once methane is produced, some may become trapped in the subsurface where it may be affected by local physical and chemical processes, while the remainder will migrate through primary and secondary porosity paths, ultimately to be vented to the atmosphere. When subsurface methane is trapped as gas, under pressure, in the presence of water or ice, it can form methane hydrate (clathrate) [16-19]. Sequestration of only a small proportion of this methane gas flux over a long period of time could result in the production of very large reserves, representing both a potential source of energy and supply of hydrocarbons for the production of chemicals and other raw materials.

On Earth, the conditions necessary for the formation of natural gas hydrates are found at depth in permafrost and beneath the ocean in continental margin sediments. Marine methane hydrate, at least that found along the tectonically passive eastern margin of North America, appears to be underlain by an active community of anaerobic methanogenic bacteria [20]. The isotopic composition of marine methane hydrate is almost always dominated by evidence of bacterial production in the Earth's deep biosphere. But methane can also be produced abiogenically, as a fractionation product of magma crystallization or by reactions with basalt or carbonate in sub-permafrost aquifers – yielding local partial pressures ranging up to many bars, depending on local permeability conditions and the availability of both carbon and water. Whatever its origin on Mars, as the planet's internal heat flow has declined with time, the resulting downward propagation of the freezing-front at the base of the cryosphere would have resulted in the incorporation any subsurface methane as hydrate -- in concentrations that may have ranged from a dispersed contaminant, to massive deposits [19].

In permafrost regions on Earth, methane hydrate and water ice form a compound cryogenic zone whose extent is determined by the local mean surface temperature, geothermal gradient, and the increase in confining pressure that occurs with depth. A Gas Hydrate Stability Zone (GHSZ) occurs within the region of the crust that satisfies these criteria, below which methane persists solely as a gas [19, 21-23]. A similar zone is defined by the subsurface temperature and pressure conditions found on Mars [19,24].

Current mean annual surface temperatures on Mars are well below freezing (ranging from ~154 K at the poles to ~218 K at the equator). At the 200 K average surface temperature of Mars, methane hydrate is not stable at a confining pressure of less than ~140 kPa [25] corresponding to the lithostatic pressure at a depth of ~15 m in. This depth defines the top of the Martian gas hydrate stability zone.. At the colder temperatures characteristic of latitudes >60°, it may be found at considerably shallower depths. Given a reasonable estimate of the thermal properties of the Martian crust, the base of the GHSZ is expected to vary from ~5-12 km at the equator, to ~11-24 km km at the poles [24]; although the base of the GHSZ may occur at much shallower depths where there is active methane venting [16] or enhanced local geothermal activity. While the size of the GHSZ can be estimated, the extent to which this stability zone is actually populated with hydrate is unknown.

In terrestrial permafrost, methane hydrate and water ice form a compound cryogenic zone whose extent is determined by the local surface temperature, geothermal gradient, and increasing pressure that occurs with depth. The region of the crust that satisfies these criteria is called the Hydrate Stability Zone (HSZ). Water ice is stable from the surface down to about zero degrees C whereas methane hydrate on Mars may be found at depths ranging from several tens of meters to as much as a km below the base of the local Martian cryosphere. Hydrate can be formed anywhere in the HSZ and high methane (or other hydrocarbon gas) fluxes can cause water-ice to recrystallize to hydrate. Relatively near-surface hydrate accumulations could also have been caused as downward propagation of the freezing-front at the base of the prograding cryosphere during the original freeze-up of Mars had the potential to have incorporated subsurface methane as hydrate - in concentrations that may range from a dispersed, low grade diagenetic mineralization, to high grade deposits formed by focused flow of methane. The extent to which the HSZ is occupied by hydrate is unclear but on Earth, shallow permafrost hydrate in commercial concentrations has been extracted for some years from Russian (West Siberian) deposits.

Because the lifetime of atmospheric methane is so short, its recent detection on Mars is generally attributed to leakage from a subsurface methanogenic biosphere although volcanic emissions from igneous fractionation could also be a source. Regardless of the source, if significant methane is being produced at depth on Mars, it is almost inescapable that much of it would be sequestered in the form of hydrate deposits in the cryosphere in a manner similar to that which occurs in permafrost regions on Earth

Identification of methane hydrate resources is vital. Exploration for subsurface hydrate on Mars can be accomplished by adapting remote sensing techniques such as seismic analysis that are currently employed on Earth. For the final phase of resource evaluation, development of remote, autonomous drilling capability will be necessary (autonomous Earth seafloor drilling capability already exists). In addition, lightweight, rapid prototyping, plastics fabrication apparatus that could be sent to Mars with early human explorers will allow a variety of life and expedition-sustaining items to be fabricated on Mars. Gas to liquid fuel fabrication apparatus will allow the natural gas to be converted to higher energy density liquid fuels for use in chemical rockets, vehicles or other local uses. In other words, a wide variety of portable industrial capability will have to be developed that can be brought to Mars to support human exploration and colonization that will utilize the subsurface methane hydrate (and CO_2) resources

Concentrated methane, water, and CO_2, along with small amounts of other chemicals (for instance, sulfur and Ca from gypsum and finely particulate iron amongst other materials) can be used to fabricate a wide variety of polymers from which accommodations, hydroponic food buildings, electric motors, vehicles and many other things that cannot conveniently be brought from Earth can be fabricated for use on Mars.

Summary: The detection of methane establishes the subsurface of Mars as a hydrocarbon province, at least in the vicinity of the plumes. Methane gas and hydrate deposits may occur in the subsurface at shallow depths on the order of ~15 - 30 m. Shallow methane gas deposits could constitute the most important near-term in-situ resource. Utilizing the natural resources of Mars could significantly reduce the cost of human exploration when compared with what would be required if these same resources were transported from Earth. In fact, the availability of these natural resources may prove to be the critical factor that will enable the continued human exploration of the solar system.

A new paradigm of a resource-rich Mars should now be considered the basis for the planning of future human exploration, whether on Mars or beyond – turning Mars from a remote, dead-end destination to a self-sustaining outpost that can serve as a stepping stone to the outer Solar System. A resource-rich Mars can be tapped for the production of high-energy fuels to return to Earth or travel further outward in the Solar System. Plastics, metals, and many other materials necessary for the sustainable presence of humans on Mars may also be secured from the planet's natural resources. The question is no longer "does Mars have resources?" but rather, "how do we assess and exploit the natural resources of Mars?", and "how can these resources support the human exploration of Mars and beyond?"

References: [1] Picardi et al. (2005), Science, 310, 1925–1928, doi:10.1126/science.1122165; [2] Plaut et al. (2007), Science, 316, 92–95, doi:10.1126/science. 1139672. [3] Boynton et al., 2002, Science vol. 297, p. 81–85. 2002 ; [4] Clifford, S. M. 1993, J. Geophys. Res., vol. 98(E6), p. 10,973–11,016. 71993 ; [5] Carr, M. H. (1996) Water on Mars: New York, Oxford University Press, 229 p. [6] Baker et al., 1992, Channels and valley networks, in Mars, in H. H. Kieffer, B. M. Jakosky, C. W. Snyder, and M. S. Mathews: Tucson, University of Arizona Press, p. 493–522. [7] Max and Clifford, 2001, Geophysical Research Letters, vol. 28, p. 1787-1790. [8] Carr, 1986, Icarus 68, 187–216 ; [9] Mumma et al., 2004; [10] Mumma et al., 2009, 2003. Sciencexpress, 10.1126/science. 1165243, 7pp ; [11] Zubrin, R. w/ R. Wagner, 1996, The Case for Mars: The Plan to Settle the Red Planet and Why We Must: New York, The Free Press, 328p.1996; [12] Fergus, 2003, Beyond Earth; living on other worlds. Special Report Research Publications (www.rps.psu.edu): The Pennsylvania State University, 16pp. [13] Formisano et al., 2004, Science, vol. 306, p. 1758–1761. [14] Krasnopolsky et al., 2004, Icarus, vol. 172, p. 537–547; [15] Krasnopolsky et al., 2009; [16] Max et al., 2006, Economic Geology of Natural Gas Hydrate: Berlin, and Dordrecht, Springer, 341p. [17] Kargel and Lunine 1998; [18] Fisk and Giovannoni, 1999; J. Geophys. Res. 104, 11805–11815; [19] Max and Clifford, 2000, Journal of Geophysical Research-Planets, vol. 105/E2, p. 4165-4171. [20] Wellsbury and Parkes, 2003; Deep Biosphere: Source of Methane for Oceanic Hydrate, in Max, M. D., ed, Natural Gas Hydrate: In Oceanic and Permafrost environments (2nd Edition): London, Boston, Dordrecht, Kluwer Academic Publishers (now Springer), p. 91-104. [21] Dickens et al., 1997, Geology vol. 25, p. 259-262. [22] Max, 2003; [23] Kargel et al., 2007; [24] Clifford et al., 2009, Journal of Geophysical Research 115, 2010, E07001, doi:10.1029/2009JE003462, 2010, [25] Sloan ED. *Clathrate hydrates of natural gases* (2nd Ed.). Marcel Dekker. Inc. New York, 1998, 628pp.