

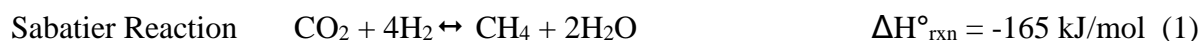
Plasma Methane Pyrolysis for Spacecraft Oxygen Loop Closure

Z. W. Greenwood

NASA, George C. Marshall Space Flight Center, Huntsville,

Life support is a critical function of any crewed space vehicle or habitat. Human life support systems on the International Space Station (ISS) include a number of atmosphere revitalization (AR) technologies to provide breathable air and a comfortable living environment to the crew. The Trace Contaminant Control System removes harmful volatile organic compounds and other trace contaminants from the circulating air. The Carbon Dioxide Removal Assembly (CDRA) removes metabolic carbon dioxide (CO₂) and returns air to the cabin. Humidity is kept at comfortable levels by a number of condensing heat exchangers. The Oxygen Generation Assembly (OGA) electrolyzes water to produce oxygen for the crew and hydrogen (H₂) as a byproduct. A Sabatier reaction-based CO₂ Reduction Assembly (CRA) was launched to the ISS in 2009 and became fully operational in June 2011.

The CRA interfaces with both the OGA and CDRA. Carbon dioxide from the CDRA is compressed and stored in tanks until hydrogen is available from OGA water electrolysis. When the OGA is operational and there is CO₂ available, the CRA is activated and produces methane and water via the Sabatier reaction shown in Equation 1.



The water product is condensed out of the product stream, separated, and purified in the Water Processing Assembly before being recycled back to the OGA to be used to produce O₂ for the crew. Methane, saturated with water vapor at a dewpoint similar to the temperature of the ISS moderate temperature cooling loop that is used to cool the condensing heat exchanger, is vented to space as a waste product. The loss of H₂ in the form of vented CH₄ and uncondensed water vapor in the CH₄ stream limits the oxygen recovery to approximately 50% from metabolic CO₂.

Without the CRA, each Crew Member (CM) requires ~0.891 kg H₂O/day to be supplied from Earth to produce breathable oxygen via water electrolysis. The CRA can theoretically reduce this figure to ~0.459 kg/CM-day but that still equates to a total water resupply requirement of ~670 kg H₂O/year for a crew of four, just for breathable oxygen. To make long duration missions beyond Low Earth Orbit logistically feasible, greater oxygen recovery from metabolic CO₂ is needed. NASA is currently targeting technologies that achieve 75-90% O₂ recovery from CO₂ [1].

One approach to achieve these higher recovery builds upon the ISS AR architecture and includes adding a post-processor to recover H₂ from CRA methane. NASA is developing the Plasma Pyrolysis Assembly (PPA) to fill of a methane post-processor [2]-[9]. The PPA uses a magnetron to generate an H₂/CH₄ plasma targeting Sabatier CH₄ conversion to hydrogen and acetylene (C₂H₂) as shown in Eq. 2. Fig. 1 shows the PPA plasma during methane processing. Secondary reactions with CH₄, as shown in Equations 3-5, and reactions with residual water vapor as shown in Eqs 6-7, also occur in the PPA resulting effluent mixture containing H₂, unreacted CH₄, product



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Fig. 1 PPA reactor chamber with hydrogen and methane plasma. in an C₂H₂,

and trace quantities of H₂O, carbon monoxide (CO), ethylene (C₂H₄), ethane (C₂H₆), and solid carbon (C).

Targeted PPA Reaction	$2\text{CH}_4 \leftrightarrow 3\text{H}_2 + \text{C}_2\text{H}_2$	(2)
CH ₄ Conversion to Ethane	$2\text{CH}_4 \leftrightarrow \text{H}_2 + \text{C}_2\text{H}_6$	(3)
CH ₄ Conversion to Ethylene	$2\text{CH}_4 \leftrightarrow 2\text{H}_2 + \text{C}_2\text{H}_4$	(4)
CH ₄ Conversion to Solid C	$\text{CH}_4 \leftrightarrow 2\text{H}_2 + \text{C(s)}$	(5)
CO Production	$\text{C(s)} + \text{H}_2\text{O} \leftrightarrow \text{CO} + \text{H}_2$	(6)
CO Production	$\text{CH}_4 + \text{H}_2\text{O} \leftrightarrow \text{CO} + 3\text{H}_2$	(7)

When H₂ recovered by the PPA is recycled back to the CRA, and the CRA is operated at a H₂:CO₂ ratio of 4.25, a theoretical O₂ recovery of >86% may be realized (assuming a respiratory quotient of 0.92) from metabolic CO₂. This further reduces the water resupply requirement to ~0.18 kg/CM-day.

In this paper the development and testing of the PPA and associated hardware is presented and discussed.

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Zachary W. Greenwood was born in Los Angeles, California [REDACTED]. He earned a bachelor's degree in aerospace engineering from the University of Colorado, Boulder in Boulder, Colorado, USA in 2008.

He is an aerospace engineer at NASA's George C. Marshall Space Flight Center in Huntsville, Alabama. His work focuses on the development of closed-loop oxygen recovery spacecraft life support systems including plasma methane processing and gas separations. In addition, he has served as the Assistant Chief Engineer for NASA Marshall's International Space Station environmental control and life support systems and has worked as a materials engineer in developing nondestructive inspection methods for aerospace materials and spacecraft.