New Power Technologies for Venus Low-altitude and Surface Missions

Ratnakumar Bugga, John-Paul Jones, Michael Pauken, Keith Billings, Channing Ahn,[1] Brent Fultz,[1] Kerry Nock,[2] Abhijit Shevade, Dharmesh Bhakta,[3] Eric Raub[3] and James Cutts
Jet Propulsion Laboratory, Caltech, 4800 Oak Grove Dr., Pasadena, Ca 91109
[1]California Institute of Technology, 1200 E California Blvd, Pasadena, CA 91125,
[2]Global Aerospace Corporation, 12981 Ramona Blvd e, Irwindale, CA 91706
[3]Eagle Picher Technologies, C Street, C & Porter Streets, Joplin, MO 64802

The *in-situ* exploration of Venus is seriously hampered by its severe environment, which is benign (25°C) at an altitude of 55 km, but rapidly becoming more hostile at lower altitudes, with temperature increasing at ~7°C/km to ~465°C and the pressure attaining 90 bars at the surface.[1] These challenging conditions have limited its in-situ exploration missions to high altitude balloons at 55 km (above the clouds) that lasted for 48 h, or even shorter duration surface missions that survived for two hours.[2,3] Both these types of missions were implemented using SOP primary batteries, and for the surface missions the batteries were even enclosed in an environmental chamber equipped with a complex thermal management subsystem just to survive for two hours. The high-altitude (55-65km) balloon missions, though successful, are stymied by the opaqueness of the Venusian clouds, which underlines the need for more long-duration in-situ missions for a better understanding of the Venus atmosphere across the cloud layers and below, and even to the surface, as recommended by the Venus science community, Venus Exploration Analysis Group (VEXAG).[4] Two types of missions, i.e., i) long-duration variable-altitude balloons with extended range below the clouds, and ii) landers with lifetimes of more than a few hours have gained particular interest. Durable Variable Altitude Balloons (VABs) will allow us to i) perform long-term measurements across Venus clouds, ii) determine the chemical species and isotopes underneath the clouds, iii) transport to different longitudes on the planet and measure atmospheric flow patterns, especially with the altitude control, iv) probe the interior structure through close-range imaging, and v) investigate the seismic activity from acoustic measurements at various altitudes. Long-durations landers, on the hand, provide more detailed and accurate information on the geology and tectonic activity of Venus.

For either of these missions, conventional power technologies are inadequate. For example, the performance of photovoltaics is hampered by the decreasing solar flux deeper in the clouds, the selective loss of short wavelength radiation, and the performance loss from the high temperatures.[5] Advanced high temperature-tolerant technologies, including photovoltaics, batteries and electronics are therefore being developed under NASA's Hot Operating Temperature Technology (HOTTech) program. An energy storage system, either rechargeable batteries or fuel cells, tolerant to high temperatures is needed to compensate the reduced power of PVs at low altitudes, and to support nighttime operations for the VABs. Likewise, new high temperature primary battery systems, survivable and operational at 465°C are required to support long-duration Venus landers, for example, the Long-life In-situ Solar systems Explorer (LLISSE) being developed by NASA-GRC

In this paper, we will describe a novel 'Venus Interior Probe using in-situ Power and Propulsion (VIP-INSPR) architecture, we have been developing under NASA-NIAC (Novel

Innovative and Advanced Concepts) program for sustained Venus atmospheric exploration. The probe utilizes: i) PV as a power source to the probe at high altitudes, and to electrolyze water carried from ground using regenerative solid oxide fuel/ electrolysis cell (SOEC), ii) Solid oxide fuel cell (SOFC)[6] to provide power at low altitudes, iii) hydrogen storage bed for on-demand storage or release of hydrogen,[7] iv) and a balloon filled with hydrogen and with hydrogen buoyancy-based altitude control system. Both H_2 and O_2 will be regenerated through electrolysis of the water produced in the fuel cell (a closed–system) at high altitudes. Additionally, these reactants will be replenished, if needed, by electrolyzing either H_2SO_4 or H_2O harvested from the Venus atmosphere at high altitudes to compensate for the loss of H_2 from the balloon and/or water from the fuel cell. This novel architecture enables generation of fuel from in-situ resources at high altitudes, power at low altitudes, and provides transport gas for the balloon. In contrast to earlier Venus probes or balloon, this probe will survive the hostile environments over the range of 60-15 km, without the need for any thermal management. Here, we will describe the preliminary design of the balloon and the suspended gondola populated with suitable instruments.

In addition to this VAB, we have been developing high temperature primary batteries for Venus surface missions under NASA's HOTTech program. These batteries are based on lithium alloys anodes (Li-Al), molten salt electrolytes based on binary/ternary mixtures of alkali metal halides, cathodes consisting of transition metal sulfides and designs similar to the aerospace thermal batteries.[8] We will present our preliminary results with FeS and FeS_2 cathodes in laboratory test cells, which are promising, showing good thermal resilience and delivering capacities >60% of theoretical values. Several new cathode materials have been identified based on the thermal stability studies, and are being evaluated for their electrochemical performance.

Acknowledgments: This work presented here was carried out at the Jet Propulsion Laboratory, California Institute of Technology under a contract with National Aeronautics and Space Administration and supported NASA-NIAC and NASA-HOTTech projects.

References

1. T. Basilevsky, J. W. ead, "The surface of Venus". Rep. Prog. Phys. 66, 1699 (2003).
2. R. Z. Sagdeev, et al., The VEGA Venus balloon experiment, Science, 231, 1407, 1986.
3. M. Wade, "Venera 1VA". Encyclopedia Astronautica. Retrieved 28 July 2010.
4. "Aerial Platforms For the Scientific Exploration of Venus", The Venus Aerial Platforms Study Team Summary Report, August 2018.
5. G. A. Landis and T. Vo, "Photovoltaic Performance in the Venus Environment," 34th IEEE Photovoltaic Specialists Conference, Philadelphia PA, June 7-12, 2009.
6. A. B. Stambouli and E. Traversa, Renewable and Sustainable Energy Reviews, 6 (2002) 433-455.
7. G. Sandrock, S. Suda and L. Schlapbach, "Applications," in Hydrogen in Intermetallic Compounds II, Topics in Appl. Phys. V. 67, Springer-Verlag 1992, ISBN 3-540-54668-5.
8. R. A. Guidotti and F. W. Reinhardt, 19th International Power Sources Symposium, Brighton, England, April 24 (1995).