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Venus should be an Earth-like planet due to its similar size and adjacent position in the solar system, but its dense atmosphere, high surface temperature, lack of water, and unique geology indicate it developed very differently. Understanding why will require in situ exploration of the planet including scientific investigation of the near surface environment where temperature extend up to 465C. Limited Venus exploration missions were carried out in the past and they are mostly orbital and short duration surface missions. Venus orbital missions were implemented with State-of-the-Practice (SOP) power systems (employing SOP solar cells & arrays) as the Venus orbital environmental conditions are benign and are similar to that of the Earth orbital missions. Short duration Venus surface missions of few hours were implemented using SOP primary batteries enclosed in a environmental chamber equipped with complex thermal management subsystem. The Russian Venera landers lasted less than 2 hours on the surface of Venus and the American Pioneer probe survived about an hour. Future emphasis for Venus *in situ* exploration is likely to focus on mid to low altitude aerial missions and long duration surface missions [1] [2]. To understand the evolutionary paths of Venus in relation to Earth, the recent decadal survey, 'Vision and Voyages for Planetary Science in the Decade (2013-2022) and the more recent VEXAG study (2014)2", emphasized the need to gather basic information on the crust, mantle, core, atmosphere/exosphere and bulk composition of Venus. More specifically, the VEXAG study recommended future explorations through in-situ investigations using low altitude aerial platforms, landers and probes.

Power Requirements: The low/altitude aerial missions and long duration surface exploration missions require new power sources capable of surviving and operating in the extreme Venus environments. The power systems that are under consideration can be classified into four categories: 1) Radioisotope Power Systems (RPS), 2) Solar Power Systems, 3) Electrochemical Power Systems, and 4) Chemical Power Systems. Wind power systems have also been considered. This paper gives an overview of the status of these SOP power technologies and examines the technical challenges associated in adopting these technologies to the future Venus aerial and surface missions.

Radioisotope Power Systems: Radioisotope power systems have been used in missions when it is not possible to use solar power systems. They have been used in several outer planetary missions and some surface missions. All the missions flown to-date have used Radioisotope Thermoelectric Generators to power the spacecraft. Four types of RTG's have used in these missions and they are: a) SNAP-19, b) MHWRTG, c) GPHS RTG, and d) MMRTG. The first three types of RTG's are not currently available for use as their production has been discontinued. MMRTG is the only RTG that is currently available for use in future missions. SOP MMRTG needs further development before it can be considered for future Venus surface missions. NASA is developing two types of advanced Radioisotope power systems: a) eMMRTG and b) ASRG. They are currently at TRL 3-4 and may be available for missions beyond 2025. They may also need further enhancements for use in Venus missions.

Solar Power Systems: High altitude aerial missions can be implemented with SOP solar power systems as the environmental conditions are not that severe. However, variable altitude (middle to low) aerial and surface missions that are currently under consideration for the next decade are very challenging because they require solar power systems that can: a) operate at high temperatures aerial environments (200-350°C) for long duration, b) survive high temperatures surface environments (450-500°C) for short duration, c) generate power at various low solar intensities (300-50 W/m2/) and Venus solar spectrum conditions encountered at various altitudes and d) survive in Venus corrosive atmospheric environments. The SOP solar cells do not function effectively in Venus aerial and surface environments and are not suitable for long duration Venus aerial missions. ARPA_E is sponsoring programs to develop high temperature solar cells required for Concentrated Photovoltaic Power system applications. These cells could further be developed to meet future Venus aerial and surface missions.

Electrochemical Power Systems: Electrochemical Power Systems have been used in a number of space missions either as a primary source of electrical power or for storing electrical energy. The energy storage technologies that have been used in space science missions are primary batteries, rechargeable batteries, capacitors and fuel cells. SOP electrochemical power systems can-not survive and operate in extreme environments of Venus. Primary Li-SO2 batteries have been used in short duration Venus surface missions. These batteries were protected from the Venus surface environment by a thermally-insulating pressure vessel in an environmental chamber along with the payload and other spacecraft subsystems. These batteries have lasted for <2 h, i.e., before the batteries were heated to their maximum survivable temperature of ~80^{o}C. Future Venus surface missions require primary batteries or fuel cells that: a) can operate at high temperatures (> 450C), b) have high specific energy (> 300 Wh/kg to provide long duration operation capability several hundreds of hours, c) survive corrosive Venus environments and d) with stand high Venus pressures. SOP thermal batteries could be modified to meet the near term mission needs. Some fuel cell systems (solid oxide and molten carbonate) are capable operating at high temperatures. They could be adopted with further development. Future mid/low aerial missions require rechargeable batteries that operate over a wide range of high temperatures (200- 450C), b) have high specific energy (> 150 Wh/kg) to reduce power system mass, c) survive corrosive Venus environments and d) with stand high Venus pressures. The rechargeable battery systems of interest include: a) sodium-sulfur, b) sodium-metal chloride, and lithium-iron disulfide. These battery systems need to be further developed to meet the needs of future Venus missions.

Chemical Power Systems: A power systems that converts heat generated from chemical reactions (lithium combustion with sulfur-hexafluoride oxidizer or atmospheric CO2) using a Stirling engine is also currently being studied [3]. This concept looks appealing in terms of specific energy, but is currently at a low TRL with quantitative verification studies yet to be done.

Wind Power Systems: While the possibility of extracting energy from the Venus environment exists, no credible concepts have yet been proposed.

Summary: A range of power choices exist for Venus in situ missions. NASA's Planetary science Division is currently completing an assessment of future needs for both solar power generation and energy storage technologies [3] that will provide more specific guidance on future needs and opportunities.

[1] Cutts, J.A., R.E. Grimm, M. Gilmore and members of VEXAG, Venus Exploration to 2050, submitted to Planetary Science Vision 2050 Workshop, December 2016. [2] Hall, J.L, M. Pauken, J.A. Cutts, K. V. Baines, R. Grimm, Future Role of Aerial Platforms at Venus, submitted to Planetary Science Vision 2050 Workshop, December 2016. [3] Miller, T.F., M.V. Paul and S.R. Olesun, Combustion-based power source for Venus surface missions, Acta Astronautica, 127:197-208, 2016 [4] Surampudi, S., Solar Power and Energy Storage Roadmap for future Planetary Missions, in preparation, 2016