“The Effective Utilization of Renewable Solar Power Systems with Regenerative Fuel Cell Energy Storage, for Commercial Applications”

Dr. Marvin Warshay
Director, Equitech International, Inc. (EII)
Cleveland, OH 44122

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by
Dr. Marvin Warshay
Consultant, Equitech International, Inc. (EII) Director
Cleveland, OH 44122

INTRODUCTION

NASA had long recognized the unique advantages of the Regenerative Fuel Cell (RFC) System to provide energy storage for Solar Power Systems in Space. The RFC System was uniquely qualified to provide the necessary energy storage for solar surface power systems on The Moon or on Mars, to use during their long periods of darkness, i.e. during the 14-day Lunar night or the12-hour Martian night. The nature of the RFC and its inherent design flexibility enables it to most effectively meet a variety of requirements of a variety of futures Space Missions.

However, in the course of implementing the NASA RFC Program (initially to provide energy storage for a planned 25kW Solar Surface Power System for the Moon) the NASA team in charge of the RFC Program at NASA Lewis Research Center (LeRC) recognized the vast number of applications for the RFC System outside of space, i.e. for government, industry, commercial, and even university applications. An efficient, environmentally benign, highly reliable, renewable energy power system is very attractive for many types of applications on the Earth as well.

To carry out the multi-application RFC Program, in the late 1980's, a unique international coalition of government, industry, and university participants was organized and led by NASA LeRC. The pioneering, multimillion dollar RFC pre-prototype system development effort by NASA led to the development of a 25kW Solar RFC Test Bed that was available to support the system development efforts of all members of the government/industry/university coalition. The flexibility of the Solar RFC System Test Bed enabled it to support not only complete Solar RFC Power applications, but also applications relying on technological advances in part of the system, i.e. on particular subsystems that made up the Solar RFC System.

THE SOLAR RFC POWER SYSTEM

The basic Solar RFC Power System consists of the Solar Power Subsystem, the RFC Energy Storage Subsystem, and the supporting subsystems (See Figure 1). The Solar Power Subsystem consists of photovoltaic (PV) arrays. The RFC Subsystem consists of the Electrolyzer Subsystem and the Fuel Cell Subsystem with reactant storage tanks. In addition, in order to maintain operation, Thermal Management and Electrical Power Management Subsystems are required for the complete Solar RFC Power System. The basic system operates as follows: When the sun shines, the Solar PV arrays not only put out enough dc power to satisfy the daytime loads, but also to supply power to the Electrolyzer Subsystem which dissociates water and stores the resulting hydrogen and oxygen gases in storage tanks. During the night, when the solar arrays are inactive, the Fuel Cell Subsystem is turned on to supply the required nighttime power loads. Fuel cells consume the stored hydrogen and oxygen and produce electricity, water, and waste heat. Of course the product water is stored and later separated back into its hydrogen and oxygen constituents by the solar-powered electrolyzer during the next daylight portion of the cycle. This describes the basic system. The next section will explain how the Solar RFC Power System can accommodate a large variety of applications by designing variations to its basic system (described above) as well as through integration with other major systems.

APPLICATIONS

As described in the previous section, the basic Solar RFC Power System is a closed system requiring no additional supply of reactants or water, which is a big advantage for many dispersed power applications, such as for ones in space. (In space the System is not thermally closed since waste heat is exhausted.) Figure 2 indicates what a Solar RFC Power System might look like on the Moon on Mars,

However, for commercial applications on the Earth it is often advantageous to use available air in the Fuel Cell Subsystem in place of the oxygen produced by the Electrolyzer Subsystem. The oxygen would be available for other uses such as for biological waste purification, hospital and home health uses, etc., many of them valuable on-site uses. A similar variation of the basic system could involve a scenario in which, at times, some of the pure water produced in the Fuel Cell Subsystem is exported in exchange for an external supply of less pure water.

One could also envisage another scenario in which the pure hydrogen generated by the electrolyzer is used to provide hydrogen fuel for fuel cell powered cars or buses. In this variation of the basic Solar RFC Power System, a less costly fuel than the usual pure hydrogen would have to be available to the Fuel Cell Subsystem. An obvious variation to the Electrical Subsystem of the Solar RFC System is the incorporation of an efficient dc to ac inverter, where ac power is required. Finally, in the Thermal Management Subsystem, where there is both opportunity and advantage, waste heat from the Fuel Cell Subsystem could be recovered (to supply space heating, heat for hot water, etc.) rather than disposing of the waste heat.

However, as potentially useful as are these variations of the Solar RFC Power System, the greatest benefits will arise from integration of the Solar RFC System with other systems, where effective integration of the Solar RFC with one or more systems will produce significant advantages over operating the systems independently. An important candidate is the Solid/Complex Waste Seam Reforming System. Dr. Terry Galloway, a Director of Equitech International, Inc. (EII), presents a detailed description of the Waste Removal Steam Reformer System in a companion paper.

The leading proponent of integrating these two Advanced Systems is Equitech International, Inc. As an outgrowth of its membership in the Solar RFC System Coalition, EII has organized a consortium of high technology companies to commercialize these two Advanced Systems. As explained by its Chairman, Mr. Dean Price, in another companion paper in this session, EII was incorporated to develop the Integrated Solar RFC Power/Waste Removal Steam Reformer System, and further integrate it with advanced industrialized building/dwelling construction and telecommunications. In his paper, he describes EII's E-MicroSystem 100kW sustainable energy concept (to serve clusters of houses, hospitals, small commercial facilities, etc. in the community), as well as its much larger E-MacroSystem concept (e.g. integrated with a coal burning power plant to form a unique combined cycle facility). An E-MacroSystem might look like what is depicted in Figure 3.

CONCLUDING REMARKS

It is clear the RFC is the key to the Solar RFC Power System. That being the case, the natural questions to the designer of such a power system are as follows: 1) Which fuel cell system should I use? and 2) Knowing that there are many types of fuel cells with varying characteristics that are under development, does the RFC application limit you to a certain type? The answer to both questions is that a fuel cell type's ability to meet application requirements, including cost and availability, will determine selection.

Currently, the low-temperature (80ºC) Proton Exchange Membrane Fuel Cell (PEMFC) is furthest along for both the Solar RFC System application (The NASA 25kW Solar RFC Test bed has an all- PEM RFC.) and the massive Worldwide Fuel Cell Electric Car technology development effort. Among the other two relatively low temperature fuel cells, the Alkaline Fuel Cell (90ºC) has been a workhorse for space applications and the Phosphoric Acid Fuel Cell (190ºC) has been making modest commercial sales in the 200 kW size for dispersed, on-site applications. An attractive characteristic of both the PEMFC and the PAFC is their demonstrated long lives under properly controlled conditions.

On the other hand, for applications where high temperature is useful, e.g. where better integration with the rest of the system could be achieved, either the 650ºC Molten Carbonate Fuel Cell or the 1000º C Solid Oxide Fuel Cell would be considered for the RFC subsystem. These high temperature fuel cell types would probably be better suited for the large E-MacrcoSystem applications than the small, dispersed E-MicroSystem applications.

In the final analysis, the selection of the RFC fuel cell type will be based on a thorough trade-off analysis, involving fuel cell type characteristics and system requirements, to determine what will best meet the applications.

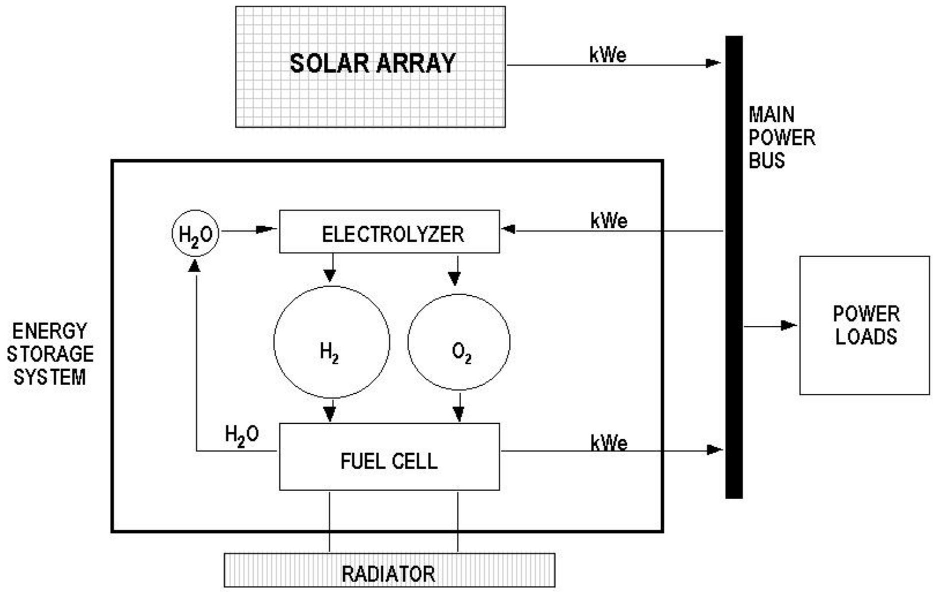

Figure 1. Schematic of Solar Regenerative Fuel Cell Power System

Figure 2. Space Application of Regenerative Fuel Cell Power System – Lunar/Mars Base

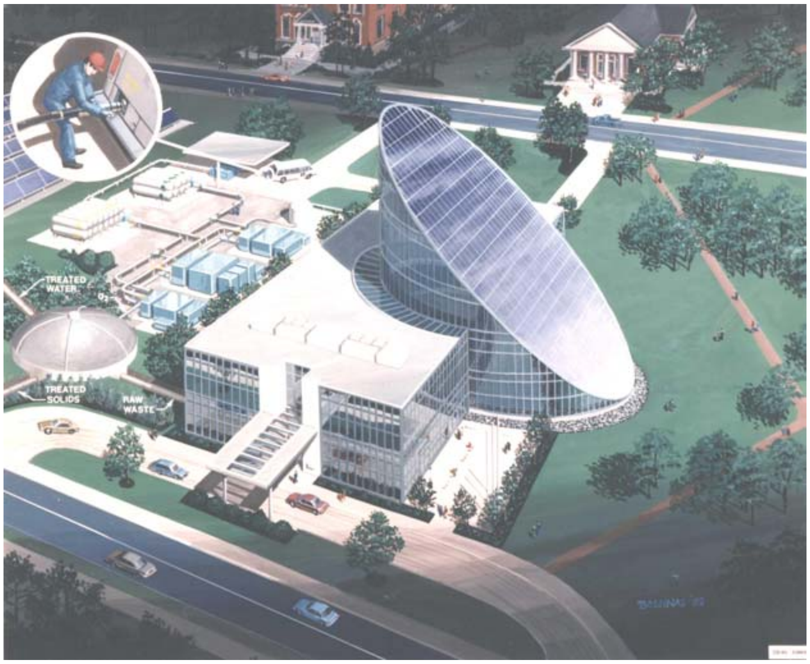

Figure 3. Commercial Application of Regenerative Fuel Cell Power System – Integrated Solar RFC/Waste Removal System