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A synergetic use of hydrogen and fuel cells in human spaceflight power systems

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ABSTRACT

Hydrogen is very flexible in different fields of application of energy conversion. It can be generated by water electrolysis. Stored in tanks it is available for re-electrification by fuel cells. But it is not only the power system, which benefits from use of hydrogen, but also the life support system, which can contain hydrogen consuming technologies for recycling management (e.g. carbon dioxide removal and waste combustion processes). This paper points out various fields of hydrogen use in a human spaceflight system. Depending on mission scenarios, shadow phases, and the need of energy storage, regenerative fuel cell systems can be more efficient than secondary batteries. Here, different power storage concepts are compared by equivalent system mass calculation, thus including impact in the peripheral structure (volume, thermal management, etc.) on the space system. It is also focused on the technical integration aspect, e.g. which peripheral components have to be adapted when hydrogen is also used for life support technologies and what system mass benefit can be expected. Finally, a recommendation is given for the following development steps for a synergetic use of hydrogen and fuel cells in human spaceflight power systems.

1. Introduction

Outer space beyond low Earth orbit holds interesting destinations for human space exploration [1], such as missions to asteroids and libration points, which require transfer vehicles operating autarkic for up to a year. Human outposts might be established on the lunar surface, either in the polar or equator region. Mars will probably the most distant destination for human spaceflight in the first half of this century. The exploration of Mars requires a dedicated transfer vehicle as well as a surface habitat.

Requirements and constraints for power generation and storage are specific for each mission. Sufficient power must be generated and eclipse phases in orbits or on surfaces make energy storage devices necessary, e.g. batteries or regenerative fuel cells. Depending on the energy and power demand, different technologies must be considered during the design phase. Whereas capacitors deliver high power for a short time (seconds to a few minutes), fuel cells and batteries can provide electrical energy for hours or days, see Fig. 1. Flywheels also offer synergetic potential between attitude control and energy storage, but this is not followed in this paper.

Abbreviations: AEL, alkaline electrolyzer; AFC, alkaline fuel cell; FC, fuel cell; EL, Electrolyzer; EPS, electrical power system; ESM, equivalent system mass; HP, high pressure; ISS, International Space Station; LF, Liquefaction; LiIon, Lithium Ion; LSS, life support system; MTV, mars transfer vehicle; PEL, polymer electrolyte membrane electrolyzer; PEFC, polymer electrolyte membrane fuel cell; RFC, regenerative fuel cell; R-, regenerative; SOEL, solid oxide electrolyzer; SOFC, solid oxide fuel cell; US, United States of America

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Symbols and units

CH_4	methane
H	(atomic) hydrogen
H_2	(diatomic) hydrogen
H_2O	water
O_2	oxygen
C	cooling demand [W]
ESM	equivalent system mass [kg]
ΔH	reaction enthalpy [J/mol]
m	mass [kg]
m'	time-dependent mass flow [kg/s]
P	power demand [W]
t	mission duration [s]
V	volume demand [m^3]
ch	charge
dis	discharge
eq	equivalency
syn	synergetic
fix	fix
re	resupply

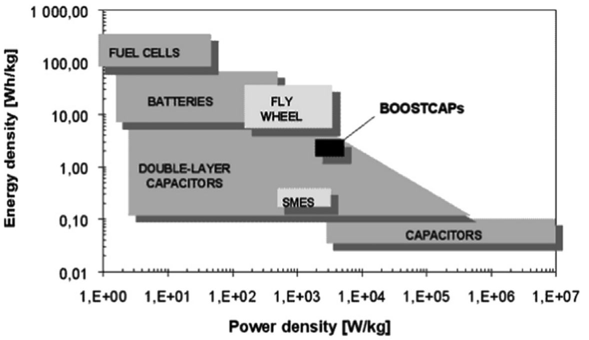

Fig. 1. Energy and power densities of typical energy storage systems in space [2].

The chemical reactions of a regenerative fuel cell (RFC) system are the fuel cell reaction (1) and water electrolysis reaction (2):

$$H_2+½O_2 \rightarrow H_2O+\Delta H \quad (1)$$

$$H_2O+\Delta H \rightarrow H_2+½O_2 \quad (2)$$

where ΔH is the reaction enthalpy of the hydrogen/oxygen (H_2/O_2) redox reaction ($\Delta H = -285.8$ kJ/mol at 1013 mbar and 298 K).

Advantage of fuel cells compared to batteries is the separation of energy and power density. Energy is chemically stored in hydrogen outside of the fuel cell. The power depends on size of the reaction are in the fuel cell. In secondary batteries, the reactants and reaction surface are assembled in one closed unit. A battery is a closed unit, so the reactants (e.g. NiH_2) never exit the unit. Fuel cells are mostly operated with hydrogen and oxygen (or oxygen containing gas like air). As the reactants supply is separated, they can be shared with other components of a spacecraft, space station or habitat.

It is not only the power system, which profits from use of hydrogen, but also the life support system (LSS), which can contain hydrogen consuming technologies for recycling management (e.g. for carbon dioxide removal and waste combustion processes). Future LSS for space exploration missions will have to focus on regenerative techniques for water and oxygen regeneration, the same matters that are used for a RFC system. Combination options of the LSS, the electrical power system (EPS) and propulsion are shown in Figs. 2–4. The first system consists of separated subsystems (Fig. 2). The replacement of the battery system by an RFC system is shown in Fig. 3. The next step can be a shared infrastructure (Fig. 4): one hydrogen (H_2) storage, one oxygen (O_2) storage and one water (H_2O) storage for all system components.

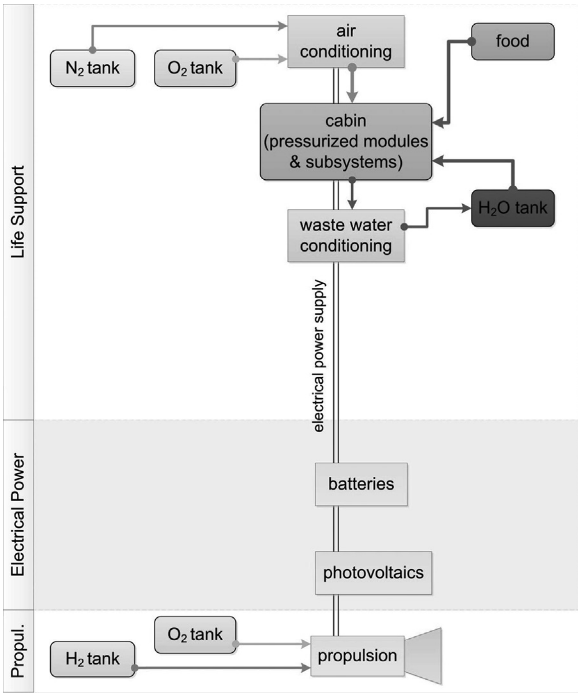

Fig. 2. Separated subsystems with batteries.

The main hydrogen producer in a LSS is an electrolyzer (EL). Future bioreactors for algae cultivation might be used for hydrogen production as well, but they are at very low energetic efficiencies of $<1\%$ nowadays [3]. The list of hydrogen consumers is quite longer, see Table 1. Especially air revitalization technologies use hydrogen, but also solid waste incineration is optimized by addition hydrogen.