



**FuelCell Energy**

World Leader in Ultra-Clean Power

## **Fact Sheet Development of Solid Oxide Fuel Cell Power Systems for Underwater Applications**

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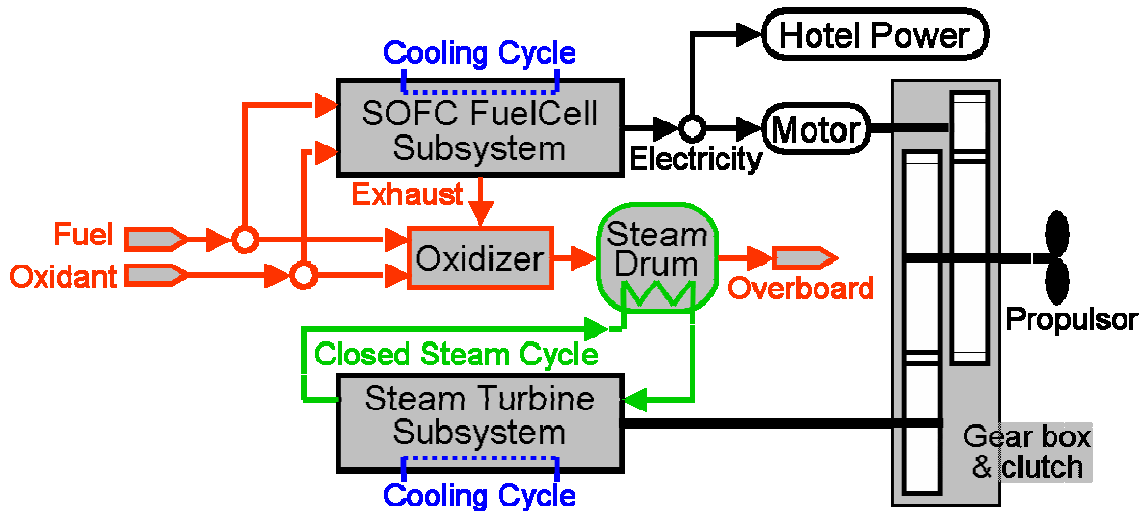
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## **Hybrid Propulsion System**

To address the Navy's need for long endurance undersea weapons, a fuel cell based hybrid propulsion system concept has been evaluated. Development of the propulsion system is being supported by the Office of Naval Research (ONR) under the STTR award titled "Hybrid Propulsion System" (N00014-06-C-0406). The system comprises a high power steam turbine section, a low power solid oxide fuel cell (SOFC) section, shared fuel and oxidant supplies, and a common drive mechanism (Figure 1). The fuel cell provides both the low speed motive power via an electric motor and the housekeeping power for guidance & control, sensors, and transmitters. The high power system activates only when high speeds are required during target prosecution.

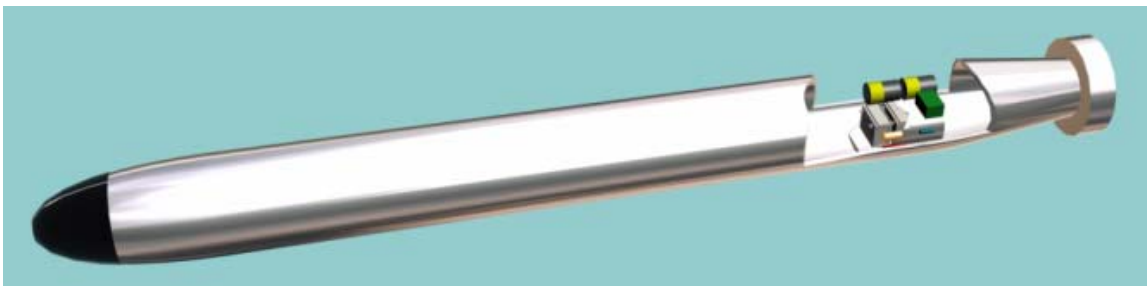


**Figure 1:** Schematic of the conceptual hybrid system:

Both propulsion systems use the same fuel/oxidant and the same gear and clutch drive train.

A conceptual hybrid fuel cell power system for undersea weapons has been developed (Figure 2). The hybrid propulsion system was designed to perform both autonomous surveillance and target prosecution for a combination of high power and low power demands. Alternative sources of fuel and oxygen were investigated. Because undersea weapons are constrained in both their gravimetric and volumetric payloads, trade studies were performed. The hybrid system for the undersea weapons has been designed to accommodate different power requirements consisting of both the high power for target prosecution and low power for long-term surveillance.

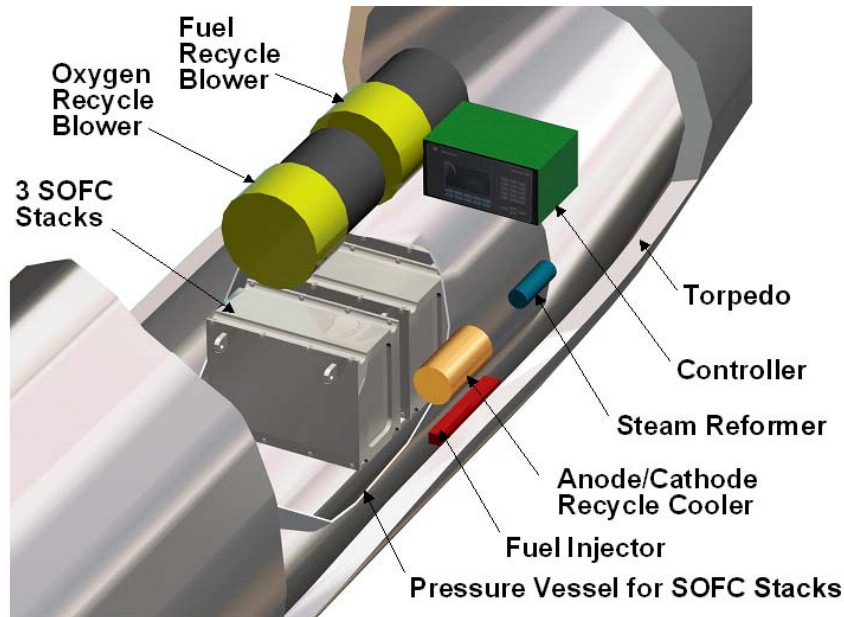
As an alternative to JP-5, use of methanol as a fuel source has been studied. Methanol has reduced fuel pre-processing requirements but only half the volumetric energy density of JP-5. Options for oxidant delivery and source of oxygen have also been studied including pressurized oxygen and lithium-perchlorate. A solid lithium-perchlorate based oxygen generator has the potential to increase the oxygen storage density by a factor of five compared to oxygen stored at 6000 psi.



**Figure 2:** Visualization of the packaged SOFC system inside an Mk-48 torpedo

In multidisciplinary design optimization studies, three oxygen storage options (high pressure gas at 3000 psi and 600 psi, and solid lithium-perchlorate) and two hybrid designs (dual turbine, SOFC) were analyzed. The most attractive design was shown to be based on JP-5 fuel, a lithium-perchlorate oxygen source, an SOFC for its low power

requirement, and a steam turbine for its high power requirement. The evaluated SOFC based hybrid systems offer in excess of a two-fold increase in electrical efficiency compared to the conventional steam turbine based systems. The reduced usages of both fuel and oxygen provide a significantly longer endurance capability, by as much as 20 times compared to a conventional Otto II fueled propulsion systems. The gain in efficiency more than offsets the penalty in fuel and the oxygen storage volumes due to the SOFC system's weight and volume. The long endurance is made possible by the SOFC system's high electrical efficiency and small package size (Figure 3).



**Figure 3:** Close-up of the conceptual SOFC system inside the torpedo shell.

The conceptual studies have indicated that an effective hybrid propulsion system consists of two parallel systems operating on the same fuel and oxidizer sources as follows:

- A high power level open combustion/closed Rankine (water based) system fueled by combustion of JP-5 liquid fuel and (LiClO<sub>4</sub> based) O<sub>2</sub> oxidizer, which provides propulsor shaft power.
- A low power system driven by an SOFC fuel cell, fueled by reformed JP-5 liquid fuel and (LiClO<sub>4</sub> based) O<sub>2</sub>, in-turn driving an electric motor suitable for propulsion, possibly by a geared connection to the propulsor shaft.

In an ongoing hybrid propulsion development effort, FCE is developing the fuel cell system including the fuel processor design and integration, Barber Nichols, Inc. (BNI) and the Applied Research Laboratory (ARL) at Penn State University are developing the oxygen generation mechanism, with ARL also evaluating requirements for the turbomachinery and design of the propulsion drive mechanism. The activities include test of a sub-scale solid oxide fuel cell stack for confirmation of performance

characteristics with simulated reformed gases and pure oxygen. The fuel cell stack, fabricated by Versa Power Systems (VPS), is planar, anode supported, with internal manifolding, metallic bipolar plates, a cross-flow configuration, and sealed with compressible ceramic gaskets. This stack consists of 6 cells each with an active area of 121 cm<sup>2</sup> (Figure 4).



**Figure 4:** Six cell SOFC stack from VPS

Other key technical issues currently being addressed are the design of a fuel cell stack module suitable for operation under pressure at deep sea, integration of the fuel processing section, and thermal management of the fuel cell stack. Current research and development includes tasks to raise the technology level of the enabling new technology components and subsystems.

The development of the fuel cell based propulsion technologies for undersea applications is an area of great interest for Unmanned Underwater Vehicle (UUV) deployment. As detailed in the UUV Master Plan, performance and endurance of the energy source are major design considerations for UUVs. The current project addresses the development of high power density systems which may eventually be deployed in underwater propulsion applications.