2011 NDIA GROUND VEHICLE SYSTEMS ENGINEERING AND TECHNOLOGY SYMPOSIUM
POWER AND MOBILITY (P&M) MINI-SYMPOSIUM
AUGUST 9-11 DEARBORN, MICHIGAN

DEVELOPMENT OF 5–10 KW JP-8 FUELED SOLID OXIDE FUEL CELL AUXILIARY POWER UNITS FOR ARMY VEHICLE APPLICATIONS

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ABSTRACT

Under the sponsorship of TARDEC, UTRC is developing 5–10 kW Solid Oxide Fuel Cell (SOFC) Auxiliary Power Units (APU) that will be capable of operating on JP-8 with a sulfur concentration of up to the specification's upper limit of 3000 ppm_w. These APUs will be sized to fit within the relatively tight space available on U.S. Army vehicles such as the Abrams, Bradley and Stryker. The objective of the base development program that commenced in August 2010 is a 1000 hour TRL-5 demonstration of an APU in an Abrams configuration by mid-2013.

This SOFC system is expected to provide power to the 28 VDC vehicle bus at a net efficiency ≥35%. In addition, the noise level is anticipated to be far below that generated by combustion engine-based APU concepts.

UTRC has completed the Preliminary Design of the system and has finalized the overall system configuration and the requirements for each of the components. During the Preliminary Design phase, evaluations of the performance of sub-scale prototypes of the desulfurizer, auto-thermal reformer, and stack were completed. In the ongoing Detailed Design phase of the program, which runs through January 2012, each of the full-scale major components will be fabricated and tested.

INTRODUCTION

A United Technologies Research Center (UTRC) led team is developing JP-8 fueled Solid Oxide Fuel Cell (SOFC) based vehicle Auxiliary Power Units (APUs). These systems are being designed to provide 28 VDC power efficiently (>35%) and quietly to vehicle electric loads when the main engine is off.

The value proposition offered by the SOFC-APUs for the vehicle applications are twofold: 1) a decreased fuel burn relative to the provision of this power by the operation of the main engine in an inefficient near idle condition, and 2) the enablement of Silent Watch missions whose durations are limited only by the vehicle fuel supply.

The high valuations placed upon fuel efficiency and silence for the envisioned vehicle application coupled with the requirement to provide the desired power from JP-8 with a sulfur level as high as 3000 ppm_w in a compact space represents an ideal scenario for the application of power dense mobile Solid Oxide Fuel Cell technology. Relative to the heat engine systems considered for the same applications, SOFCs offer large ($\Delta>10\%$) efficiency advantages, and they are anticipated to offer appreciable acoustic benefits as well. On the other hand, relative to other fuel cell based technology, due to their high (~800°C) operating temperature, SOFC stacks can effectively operate on H_2 and CO rich reformate streams and are more tolerant of reformate "impurities" (e.g. S) in sharp contrast to other lower operating temperature stack technologies. As a consequence of this increased tolerance, SOFC systems can feature significantly more compact liquid hydrocarbon fuel processors than other technology options.

However, while the high temperature operation of SOFCs is beneficial from a fuel processing standpoint, it presents an operational challenge in that the system must be brought up to this operating temperature before power generation commences. At present, this heat-up process is required to take approximately 30 minutes, and the UTRC team is working toward this target.

SYSTEM CONCEPT

UTRC has been working since 2006 under Air Force Research Lab (AFRL), TARDEC, and Defence Science and Technology Agency (DSTA) of Singapore sponsorship on the development of compact and lightweight SOFC systems, Figure 1, for both Unmanned Aerial Vehicle (UAV) propulsion and vehicle auxiliary power applications that operate on low sulfur liquid hydrocarbon fuels—including S-8, Ultra-Low Sulfur Diesel (ULSD), and desulfurized JP-8. The major focus of the development effort has been to drive mass and volume from the SOFC systems while maintaining their efficiency advantage relative to the internal combustion engine competition for the applications. In the interest of minimizing system weight and volume at the cost of a reduced efficiency, these 1–2 kW scale systems have featured Catalytic Partial Oxidation (CPOX) fuel reformers.

Under the sponsorship of the Office of the Secretary of Defense (OSD) Energy Security Task Force and with program management provided by the Office of Naval Research (ONR), UTRC migrated its lightweight SOFC system technology to 12 kW Marine Ground Generator applications, where operation on low-sulfur (< 400 ppm_w) JP-8 and JP-5 is required, and the reduced importance of system weight in such ground applications enables the incorporation of additional efficiency enhancing features such as anode recycle. During the ONR sponsored activity, UTRC completed the Detailed Conceptual Design of the Ground Generator and experimentally demonstrated several of the major component technologies including a power dense SOFC stack, an auto-thermal reformer fed by a high-temperature recycle loop, and a fully regenerable fuel desulfurizer.

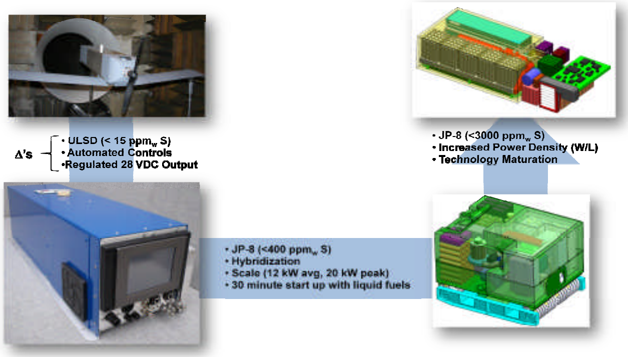

Figure 1: Migration of UTRC lightweight mobile SOFC technology to Army vehicle applications

In the current vehicle application, the ONR Ground Generator Design has been updated to enable operation on JP-8 with a sulfur level as high as 3000 ppm_w and to enable the system to fit within the confines of the available vehicle space claim. The system concept is illustrated in Figure 2, where the system flow sheet is presented. The system is projected to have an efficiency in excess of 35% (LHV-basis) and be capable of starting and operating at the range of ambient conditions specified in MIL-STD-705C while operating on JP-8 fuel with the characteristics specified in MIL-STD-83133F. Lastly, the only maintenance task anticipated at the minimum required maintenance interval is the replacement/cleaning of the inlet air and fuel particulate filters.

The system features a power dense anode supported stack module, an auto-thermal reformer whose steam supply is drawn from the anode exhaust via a high temperature recycle blower, a fully regenerable fuel desulfurizer/vaporizer and a high temperature chromium-free oxide coating (900°C) heat exchanger.

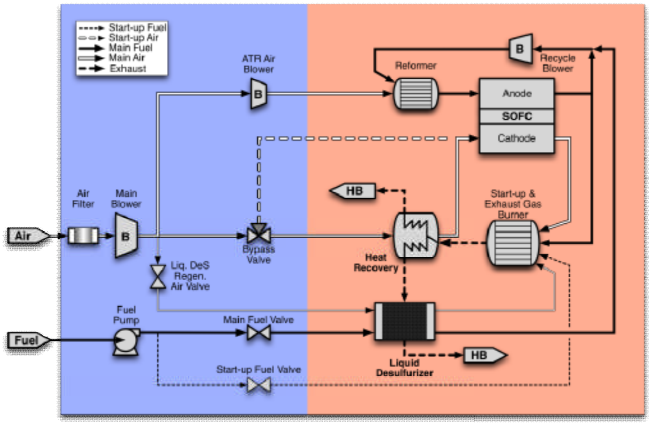

Figure 2: SOFC APU System Concept

DEVELOPMENT PROGRESS

Thus far, each of the major component technologies has been demonstrated in subscale testing. Full scale component design and performance evaluation is underway. Development progress on three of the major components is summarized in the remainder of this section.

Regenerable Fuel Desulfurizer

The system features a fully-regenerable fuel desulfurizer that will be provided by Aspen Products Group. This packed bed system converts liquid JP-8 with a sulfur level as high as 3000 ppm_w to a vapor stream of desulfurized JP-8 with a sulfur concentration of $< 15\ \text{ppm}_w$.

This elevated temperature reactor sub-system has been fully thermally integrated into the SOFC system so that waste heat from the stack fuel conversion process is used to maintain the reactor at its design temperature.

Thus far, an approximately half-scale advanced reactor prototype has been designed, fabricated and demonstrated to provide the desulfurization performance anticipated for the available fuel sulfur levels.

Auto-Thermal Reformer (ATR)

The auto-thermal reformer converts a mixture of fresh fuel, ambient air and recycled anode exhaust to a hydrogen and carbon monoxide rich reformate stream that may be converted by the stack module to DC electric power.

Thus far, an approximately half-scale reformer has been built and evaluated in both stand-alone and anode recycle loop sub-system tests that also included a sub-scale stack and recycle blower.

In both the reformer and sub-system tests, the reformate composition was monitored via both online gas analyzers and intermittent gas chromatograph analyses of bomb gas samples. These composition measurements were used to determine both the overall conversion efficiency and to assess the likelihood of carbon deposition (coking) from the reformate stream in the stack inlet manifold.

In the stand-alone tests, which were conducted using the desulfurized JP-8 fuel that the reformer will be supplied with during system operation, the reformer demonstrated a JP-8 fuel to reformate conversion efficiency of 94% with a composition deemed to be of low coking risk. Additionally, in preliminary durability testing, the reformer was operated successfully at the target operating point for a period of 50 hours. Extended durability testing is planned for later this summer.

After the abovementioned standalone reformer testing, the auto-thermal reformer was inserted into the sub-scale anode recycle sub-system illustrated in Figure 3, and the performance of the complete sub-system was evaluated. In this sub-system test, the system demonstrated the gross efficiency performance anticipated (~45%) at the current densities achievable in the test configuration, where the gross efficiency is defined as the ratio of the gross DC stack power to the lower heating value of the desulfurized JP-8 being supplied to the system.

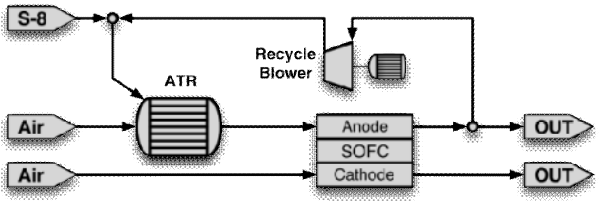

Figure 3: Idealized anode recycle loop sub-system test configuration.

Power Dense SOFC Stack

A sub-scale version of the SOFC stack module has been fabricated and evaluated experimentally in both standalone and sub-system tests with the reformate composition anticipated in the full-scale system. In these experiments, the stack has demonstrated a performance consistent with the system efficiency and power targets.

NEXT DEVELOPMENT STEPS

In the next phase of the program, full-scale versions of each of the major components will be fabricated and tested in preparation for the Detailed Design review. Complete full-scale system testing is anticipated in the second half of 2012.