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BREAK

DEVELOPMENTAL STATUS OF HYBRIDS

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ABSTRACT

Fuel cells are emerging as a major new power generation technology that is particularly suitable for distributed power generation, high-efficiency, and low pollutant emission. An interesting combined cycle, the "HYBRID," has recently been scoped "on paper" that portends the potential of ultra-high efficiency (approaching 80%) in which a gas turbine is synergistically combined with a fuel cell into a unique combined cycle. This paper introduces hybrid technology to the gas turbine community as a whole, and summarizes the current and projected activities associated with this emerging concept.

INTRODUCTION

A "HYBRID" is a power generation system in which a fuel cell is combined with a gas turbine. The net result is a synergism in which the combination performs with an efficiency that far exceeds the sum of the two. While a hybrid has yet to be demonstrated, the hybrid system has been extensively analyzed and studied "on paper" over the past five years by the Department of Energy, industry, and the National Fuel Cell Research Center (NFCRC). These efforts have revealed that the synergism of this combination is capable of remarkably high efficiency. This attribute, combined with an inherent low level of pollutant emission, suggests that hybrid systems are likely to serve as the next generation of advanced power devices.

This potential, while impressive, will require substantial development of balance of plant and infrastructure, and resolution of major technical hurdles. Given what we presently know about hybrids, a variety of technical issues are likely to emerge:

- High temperature heat exchanger and improved materials will need to be developed.
- A new turbine design will be required with adjusted pressure ratios, firing temperatures, and operating conditions in order to optimize the cycle efficiency and reduce costs.
- Recuperation and intercooling development will be needed.
- High temperature combustors and fuel systems will be needed for fuel-lean operation and startups with integrated systems.
- Systems reliability and operability must be established and optimized for selected cycles. This includes startup, matching loads, and systems upsets.

Although developing hybrid power cycles will be a formidable task, the basic building blocks needed are already becoming available. These building blocks are the subsystems being developed by partnerships between FETC and U.S. industry including advanced turbine systems and fuel cells. By carefully integrating these subsystems or modules, and solving the remaining technical challenges, hybrid power cycles with efficiencies of 60% and higher that meet the required emissions and cost criteria can be realized.

FUEL CELLS

A fuel cell generates electricity very efficiently by using an electrochemical reaction rather than a heat engine driven by combustion. Because the efficiency of a fuel cell is not limited by the thermodynamic constraints placed on heat engines, a fuel cell would be the likely core of a high-efficiency hybrid power cycle. Fuel cell systems are expected to play an important role in meeting future distributed generation (DG) market needs. Fuel cells have wider applicability than DG and other market segments are being targeted with a variety of possible fuel cell products.

The fuel cell's electrical energy conversion efficiency ranges from 40 to 60 percent lower heating value (LHV). Combined with a gas turbine, efficiencies of over 80 percent LHV are potentially possible. The fuel cell operates at high efficiency, regardless of size and load, and the by-product heat from fuel cell

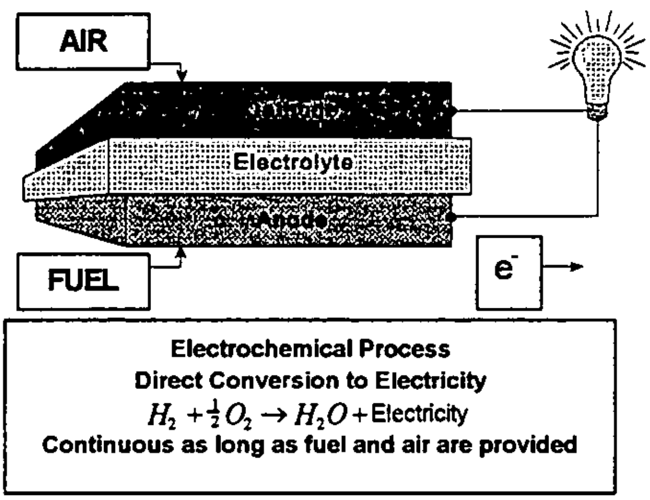

Figure 1: Fuel Cell

Fuel cells that are especially attractive for hybrid operation include those, such as solid oxide and molten carbonate, which operate with high temperature exhaust flows. The gas turbine can be utilized, for example, to extract energy from the exhaust flow. The gas turbine can also be used to pressurize the fuel cell.

The fuel cell and gas turbine can be configured in several different fashions. In one particularly simple concept, the air stream is first pressurized through the compressor of the turbine. The pressurized air stream is then fed to a fuel cell, fuel is added, and the resultant electrochemical reactions lead to the direct production of electrical energy. The elevated pressure operation leads to an improvement of both efficiency and power density. The relatively hot fuel cell exhaust gases are expanded in the turbine to provide the compressor work, and to produce even more electrical energy. This effective utilization of "waste heat" further increases overall cycle efficiency.

Additional concepts promise efficiencies of over 80%. For example, fuel cells may be networked, placed in series as well as in parallel, with a further increase in the overall system efficiency.

ADVANCED TURBINE SYSTEMS

Gas turbines and heat engines will continue to be a key component in power generation systems during the next century. By the year 2000, the US DOE Advanced Turbine Systems (ATS) program will provide the cleanest, most efficient gas turbine combined cycle power plant on the commercial market. However, under the present ATS program, the gas turbine progress needed to meet hybrid power cycle goals (e.g., fuel flexibility, performance, and cost) will not be attained. Hybrid power module goals will only be realized with a long-term program which results in the transfer of high-risk technology into existing advanced gas turbine products. Furthermore, fuel cells have extremely low gaseous pollutant emissions.

Gas turbine and engine systems will achieve their optimum performance and cost levels through the development and use of advanced cycle configurations coupled with increased pressure ratios, improved alloys and ceramic materials, high-efficiency cooling designs, and combustion technology such as lean pre-mix and catalytic systems. These crosscutting, high-risk, technologies may be transferred to heavy frame and aeroderivative gas turbine product lines and advanced gas engines, resulting in significant reductions in electricity cost, pollutant emissions, and fuel consumption. Ultimately, these turbines can be designed to utilize hydrogen fuels, providing essentially "zero" emissions. Enhanced engines will constitute the power modules needed for distributed power systems and hybrid concepts, and can also be used to repower or replace inefficient existing systems to further reduce U.S. greenhouse gas emissions. These systems advanced gas turbine systems will have a significant impact on global greenhouse gas emissions as they can serve international as well as domestic power market needs. The hybrid portends to have a particularly dramatic impact.

STATUS OF HYBRID DEVELOPMENT

Several cycle configurations have been presented or patented for hybrid systems. Many of these systems show tremendous promise for ultra-high efficiency. However, feasibility assessments and analyses are needed to determine which cycles are the best candidates for the various markets and applications.

First generation hybrid systems

FETC has a cooperative agreement with Siemens-Westinghouse to develop a 60% efficient (LHV) fuel cell-gas turbine power system. Under this agreement, Siemens-Westinghouse has determined that suitable gas turbines in the 150-220 kW size range will need to be developed for integration with the solid oxide fuel cell. These systems are expected to be commercial by the year 2003-05.

MW Class High Efficiency Fossil Fuel Power Plants

FETC recently held two public workshops to evaluate the potential and technical barriers for development of an ultra high efficiency hybrid system. As a result, FETC issued a Program Research & Development Announcement (PRDA) for a conceptual design and feasibility study of possible high efficiency fossil-fueled power plant concepts. Only near term systems of less than 20 MW were considered. These systems were also to be

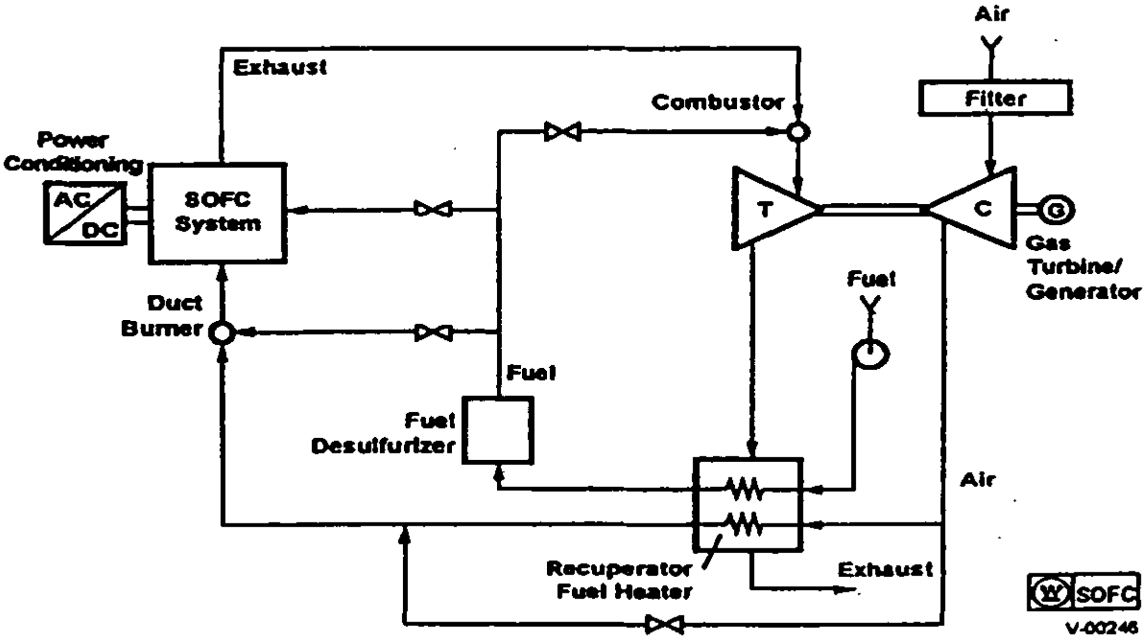

Figure 2: First Generation Hybrid System

at least 70 percent efficient (LHV) at converting fossil fuel to AC electricity and produce electricity at costs 10 to 20 percent below today's conventional plants.

In the summer of 1998, five hybrid feasibility studies were initiated (Table 1). A team lead by M-C Power and another consisting of Bechtel, IGT, and Rolls Royce Allison Engine Company, will determine the technical and economic feasibility of a 20 MW combined cycle. The cycle includes a natural gas-fueled molten carbonate fuel cell bottomed by a gas turbine. Fuel Cell Engineering Corporation with Energy Research Corporation and Rolls Royce Allison Engine Company will also evaluate a carbonate fuel cell-gas turbine bottoming cycle in combination with a steam turbine generator, and a fuel cell bottoming a fuel cell. Siemens-Westinghouse Power Corporation has teamed with (1) Rolls-Royce Allison Engine Company to evaluate a pressurized solid oxide fuel cell coupled with conventional gas turbine technology in a completely dry (no boiler or steam bottoming power cycle) power plant, and (2) Solar Turbines Inc. to evaluate a hybrid system based on integration of the Solar Mercury 50 ATS with a pressurized SOFC generator. McDermott is teaming with NREC to evaluate a SOFC-recuperated combined cycle hybrid system.

The US DOE Office of Fossil Energy and Office of Energy Efficiency and Renewable Energy are sponsoring these studies to evaluate the technical and economic feasibility of 70% efficient fuel cell - gas turbine hybrid systems. The DOE Federal Energy Technology Center (FETC) envisions these systems to be available for demonstration by the year 2003 and commercially available by the year 2007.

Table 1.
Awards for Fuel Cell and Gas Turbine Systems PRDA

Fuel Cell Manufacturer	Turbine Supplier	Type of Fuel Cell
Siemens Westinghouse Power Generation	Rolls Royce Allison Engine Company	Tubular Solid Oxide
Siemens Westinghouse Power Generation	Caterpillar/Solar Turbines	Tubular Solid Oxide
Energy Research Corporation	Rolls Royce Allison Engine Company	Molten Carbonate
M-C Power	Rolls Royce Allison Engine Company	Molten Carbonate
McDermott/SOFCO	Northern Research & Engineering Corp	Planar Solid Oxide

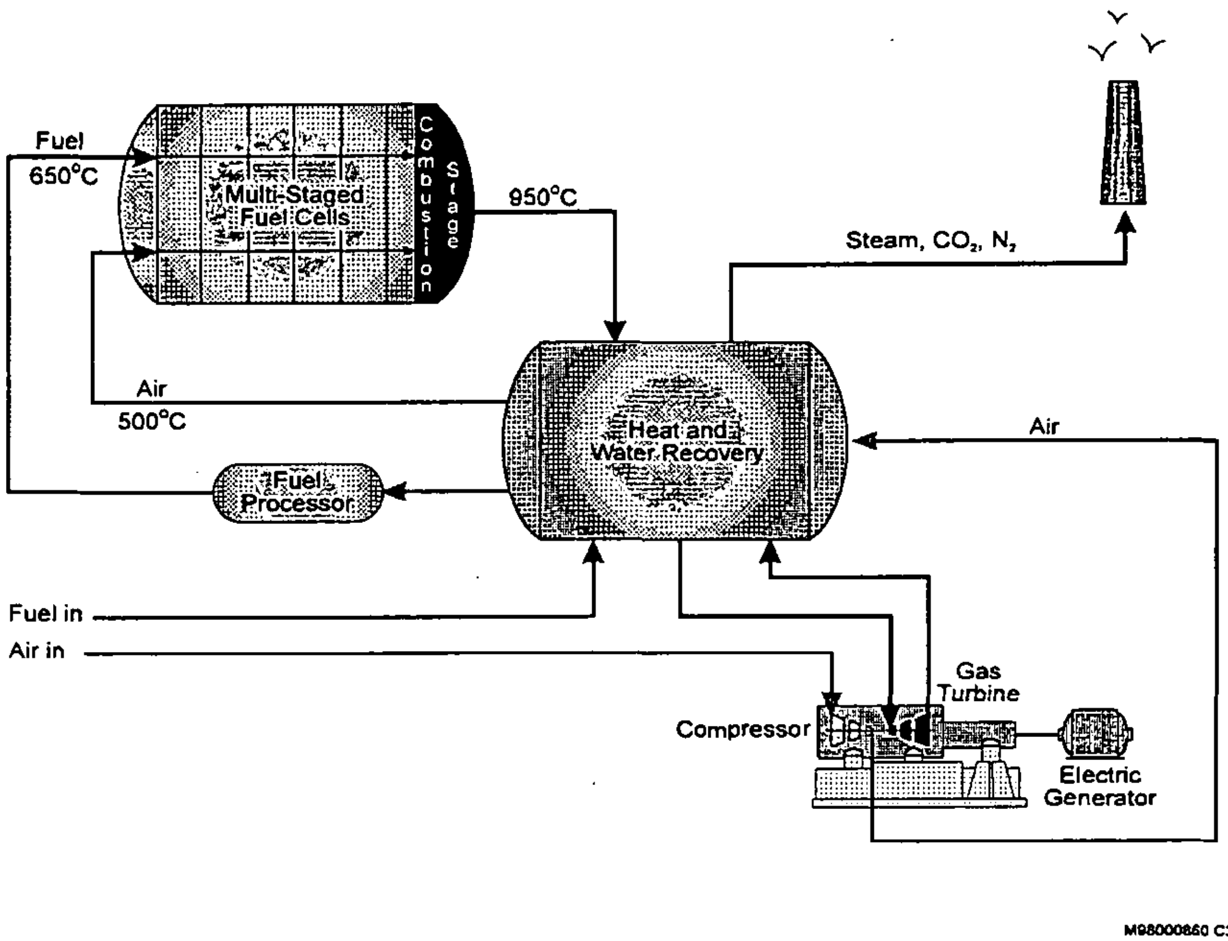

Figure 3: UltraFuelCell Concept

As part of its strategic planning, FETC periodically looks at conceptual power generation systems that could evolve into new product line possibilities. Design parameters (e.g., lower temperature solid oxide operation, staged solid oxide fuel cells, oxygen enrichment of air, and integration of fuel cells with high performance gas turbines, using cathode gas recycle blowers if required) are used to configure systems and compute key performance factors relevant to its economics.

In FY98, several new fuel cell/gas turbine systems concepts were identified by FETC utilizing fuel cell products both internal and external to the existing product line. Counting the PRDA-related systems and those from FETC, twelve possible new fuel cell/gas turbine system concepts have been identified. In parallel with the studies conducted in FY99 under contracts resulting from the PRDA, FETC will evaluate these additional FETC-conceived concepts and determine the potential for system improvement.

Hybrids based in the Ultra-Fuel Cell Concept

The Ultra-Fuel Cell concept is the next generation of fuel cell. Utilizing the Ultra-Fuel Cell, the next generation of hybrid system may be developed with advanced gas turbines or other power generation devices. FETC and NFCRC analyses predicts that these systems can be up to 80% efficient and could be commercially available by the year 2015. Long term research and development is needed to ensure that the Ultra-Fuel Cell concepts are feasible and can be demonstrated by the year 2010.

Systems studies are continuing at FETC and the NFCRC to develop even higher efficiency systems. In FY1998, for example, FETC developed the UltraFuelCell concept and conducted several studies to confirm its validity and to quantify potential costs and technical advantages. Though the initial study was conducted at 4-MW scale with stationary power plants in mind, it has become apparent that the cycle is simple enough that it will likely have many applications, especially when solid oxide technology power densities reach three times the current state-of-the-art. At such time, the size of a solid oxide tube or cell array would approach that of competing internal combustion engines. The concept justifies a 5 to 10 year research program to develop seals for the oxide fuel cell and to develop materials (namely electrolytes) that can operate at lower temperature (600-650°C). A major FY1999 goal is to confirm that inlet temperatures of

700°C will yield 80% efficiency in which case a 5-6 year development plan is highly probable.

FETC has established a team to lead a joint industry-government-university collaborative effort to develop the UltraFuelCell system. In FY1999, FETC held a workshop to disseminate plans and to solicit comments and support for the UltraFuelCell. The goal of the workshop was to cultivate stakeholder support for a multi-year R&D program, the goal of which will be a quantum leap in system efficiencies in conjunction with dramatic reductions in cost.

CONCLUSION

Hybrid power systems based on combining fuel cells with gas turbines provide tremendous opportunity to reduce pollutant emissions, the emission of carbon dioxide, costs, and fuel use associated with energy conversion to heat and power. Successful hybrid plants can provide an option to meet the growing needs of electricity, domestically and internationally, and with less environmental impact than current technology. Initially, hybrid power plants less than 20 megawatts in size, suitable for distributed power generation, will be developed. The hybrid plants will produce electricity at costs 10 to 20 percent below today's conventional plants, as well as reducing emissions of both air pollutants and greenhouse gases.