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High Efficiency Carbonate Fuel Cell/Turbine Hybrid Power Cycles

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High Efficiency Carbonate Fuel Cell/Turbine Hybrid Power Cycles

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Abstract

Carbonate fuel cells developed by Energy Research Corporation, in commercial 2.85 MW size, have an efficiency of 57.9 percent. Studies of higher efficiency hybrid power cycles were conducted in cooperation with METC to identify an economically competitive system with an efficiency in excess of 65 percent.

A hybrid power cycle was identified that includes a direct carbonate fuel cell, a gas turbine and a steam cycle, which generates power at a LHV efficiency in excess of 70 percent. This new system is called a Tandem Technology Cycle (TTC). In a TTC operating on natural gas fuel, 95 percent of the fuel is mixed with recycled fuel cell anode exhaust, providing water for the reforming of the fuel, and flows to a direct carbonate fuel cell system which generates 72 percent of the power. The portion of the fuel cell anode exhaust which is not recycled, is burned and heat is transferred to the compressed air from a gas turbine, raising its temperature to 1800 °F. The stream is then heated to 2000 °F in the gas turbine burner and expands through the turbine generating 13 percent of the power. Half the exhaust from the gas turbine flows to the anode exhaust burner, and the remainder flows to the fuel cell cathodes providing the O₂ and CO₂ needed in the electrochemical reaction. Exhaust from the fuel cells flows to a steam system which includes a heat recovery steam generator and staged steam turbine which generates 15 percent of the TTC system power.

Studies of the TTC for 200-MW and 20-MW size plants quantified performance, emissions and cost-of-electricity, and compared the characteristics of the TTC to gas turbine combined cycles.

A 200-MW TTC plant has an efficiency of 72.6 percent, and is relatively insensitive to ambient temperature, but requires a heat exchanger capable of 2000 °F. The estimated cost of electricity is 45.8 mills/kWhr which is not competitive with a combined cycle in installations where fuel cost is under \$5.8/MMBtu. Emissions from the TTC are well below existing or proposed standards. Based on equilibrium levels the TTC NO_x emission level is 25 percent of the level from a combined cycle. The SO_x level from a TTC is 4 percent of the level from a combined cycle because the sulfur is removed from the fuel used in the fuel cells. The CO₂ emission is 25 percent below the combined cycle reflecting the improved efficiency.

A 20-MW TTC plant for near-term application was studied in which a moderate (1500 °F) temperature heat exchanger was used, and steam was provided from the steam system rather than by recycle of the anode exhaust. This TTC system has an efficiency of 65.2 percent and a cost-of-electricity of 50 mills/kWhr, and is competitive with a combined cycle for fuel costs above \$2.5/MMBtu. Emissions from the 20-MW TTC are well below existing or proposed standards.

A 20-MW TTC plant can be implemented without significant development for applications in the year 2001 and beyond. Development needs include design studies to optimize the system process and develop a plant layout, and design studies on gas turbine design modifications. The next logical step would be a 20-MW plant demonstration with existing technology.

Objectives of Advanced Technology Cycle Studies

- Joint ERC/METC evaluation of 200-MW Direct Fuel Cell/Turbine Hybrid System
- ERC evaluation of 20-MW Hybrid System
- Goals are (1) high efficiency, and (2) competitive cost

Tandem Technology Cycle, Simplified Schematic

2.85-MW Commercial Power Plant Layout

Tandem Technology Cycle

Tandem Technology Cycle Performance

200-MW Plant Study Results

- Power Generation, MW

Gas Turbine	27.1
Fuel Cell	157.6
Steam Turbine	32.8
Parasitic Power	-11.1
Total	206.4

- Net AC LHV Efficiency, %

Fuel Cell	55.1
FC + GT	61.7
Steam System	34.1
Overall	72.6

Air Temperature Versus Power Output
Tandem Cycle Power Output Remains Within 4 Percent

Levelized Cost of Electricity, 200-MW System
(1995 dollars, without inflation)

	Levelized Cost (mills/kWhr)
Fuel	21.4
Plant	12.5
O&M	12.1
Total	46.0

Cost of Electricity, Tandem Cycle Versus Combined Cycle

Conclusions: 200-MW Tandem Cycle

- LHV Efficiency above 70 percent achievable for large systems
 - Requires 2000 °F heat exchanger
- Good performance over a large range of ambient conditions
- Competitive with combined cycle at fuel costs above \$5.80/MMBtu
- NO_x emissions well below existing or proposed standards

Near-Term System:

- Moderate temperature heat exchanger (1500 °F)
- No anode recycle
- 20-MW size

Tandem Technology Cycle Alternative, Without Anode Recycle

Performance of Tandem Technology

Power Generation, MW	200 MW	20 MW
Gas Turbine	27.1	4.2
Fuel Cell	157.6	14.3
Steam Turbine	32.8	4.1
Parasitic Power	-11.1	-0.8
Total	206.4	21.8

Efficiency of Tandem Technology

Net AC LHV Efficiency, %	200 MW	20 MW
Fuel Cell	55.1	56.8
FC + GT	61.7	52.9
Steam System	34.1	29.7
Overall	72.6	65.2

Levelized Cost of Electricity, 20-MW System (1995 dollars, without inflation)

	Levelized Cost (mills/kWhr)
Fuel	23.8
Plant	13.2
O&M	13.0
Total	50.0

Cost of Electricity, Tandem Cycle Versus Combined Cycle

Conclusions: 20-MW Tandem Cycle

- LHV efficiency of 65 percent achievable with existing technology
- Competitive above \$2.50/MMBtu fuel cost
- NOx emissions well below existing or proposed standards
- Can be implemented, near term (year 2001 and beyond) without significant development

Development Needs

- Design studies: (1) optimization and plant layout; (2) gas turbine design modification
- 20-MW demonstration with existing technology