Review of DOE Hybrid Systems Activities

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Definition of Hybrid System

- **Not a Combination of Reciprocating and Electrical Engines**
- **Is a Combined Cycle Containing a High-Temperature Fuel Cell +**
  - Gas Turbine
  - Reciprocating Engine
  - Another Fuel Cell

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Drivers for Hybrid Systems

- Optimized System 70%+ Efficient
- Can be Environmentally Pristine
- Attractive COE
- Near-Term Components

Early Work

- Initially Conceived in Late 1980s - Early 1990s
- Workshops in Morgantown in 1995 & 96
- Hybrid PRDA Solicitation 4/97
- Westinghouse FC Contract Signed on 8/22/97

FETC Internal Activities

- **In-house**
  - Integration of Fuel Cells and Gas Turbines
  - Dynamic Performance of Hybrid Systems
- **Process Engineering Division**
  - Comparison of Hybrid Concepts
  - Framework Convention for Consistent Evaluations

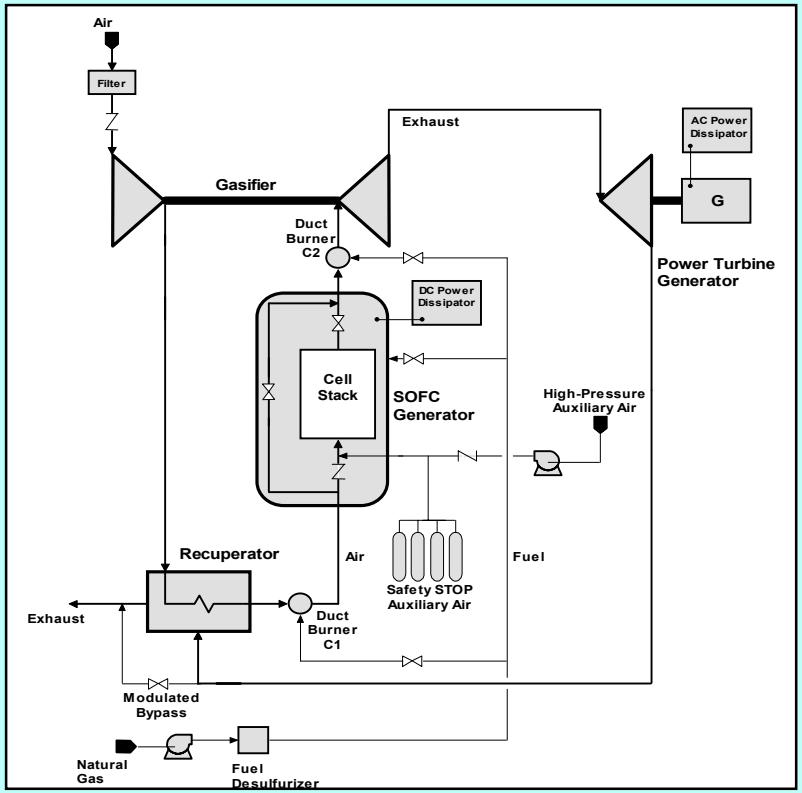
Siemens Westinghouse - 1st Generation Hybrid System

Projected Performance:

57% Efficiency (LHV)

Less than 1 ppm NOx

220 kWe Pressurized SOFC/GT Power System Cycle



Notes

Pressure = 3 ATM

C1 and C2 burners are only used for startup

Siemens Westinghouse 1st Generation

- **Established Fuel Cell Design:**
  - More than 8 Years of Development and Testing at Atmospheric Pressure
  - More than 6,000 Hours of Commercial Performance at 100 kW and Atmospheric Pressure
  - More than 5,000 Hours of Pressurized Testing up to 15 Atmospheres Pressure

Siemens Westinghouse 1st Generation Status

- Process and Control Test of Turbine and Fuel Cell Volume in Progress
- Factory Acceptance Test 12/99
- Site Acceptance Test at NFCR Center 2/16/2000
- Proof-of-Concept Test (1,000 hrs) 2/23/2000
- Initial Commercial Offering 2002

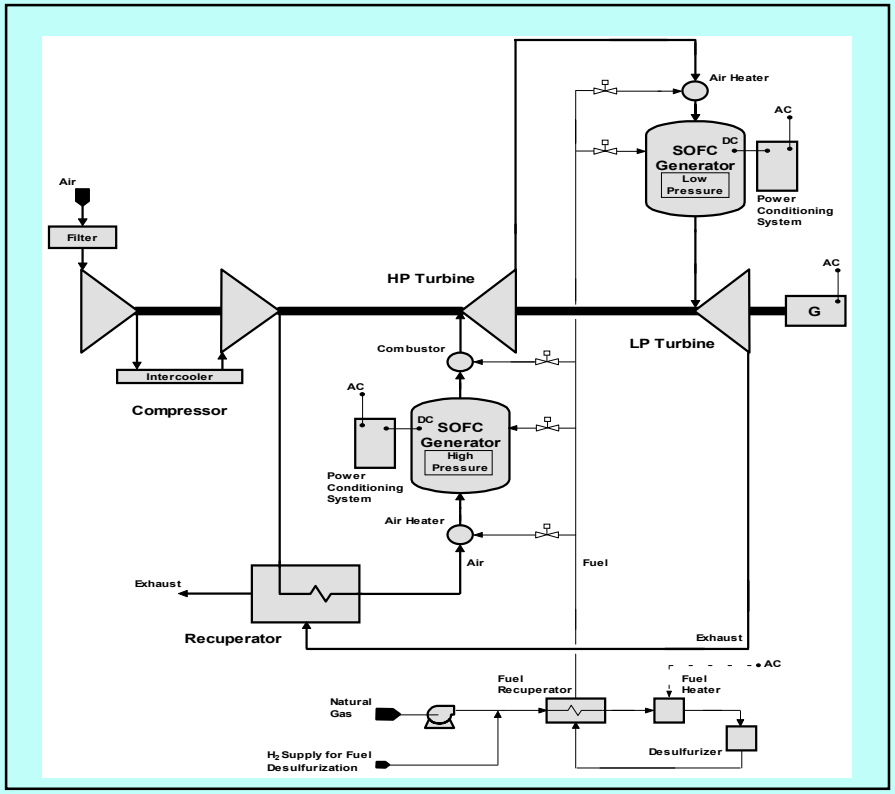
PRDA Selection Guidelines (FE and EE Funding)

- 20 MW
- 70% Efficient
- Near-Term Components
- Must Contain a High-Temperature Fuel Cell
- Operate on Natural Gas
- Cost of Electricity at Least 10% Less Than Conventional Systems

Awards for Fuel Cell/Gas Turbine Systems PRDA

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

Pressurized SOFC/Reheat Gas Turbine Power System Cycle (SWPC)



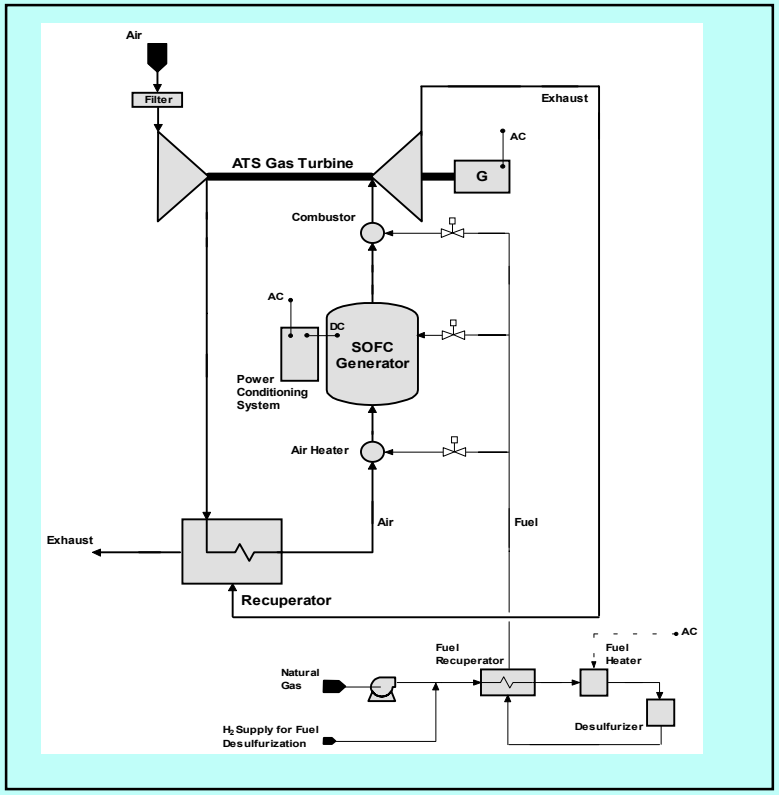
Notes

Pressure = 7 ATM

Siemens Westinghouse/Allison Results

- 67% Efficient as Developed
- 70% Efficiency Achievable with Improvement in Component Design
- COE is Comparable to Present-Day Alternatives
- NOx Less Than 1 ppm

Pressurized SOFC/ATS Gas Turbine Power System Cycle (SWPC)



Notes

Pressure = 9 ATM

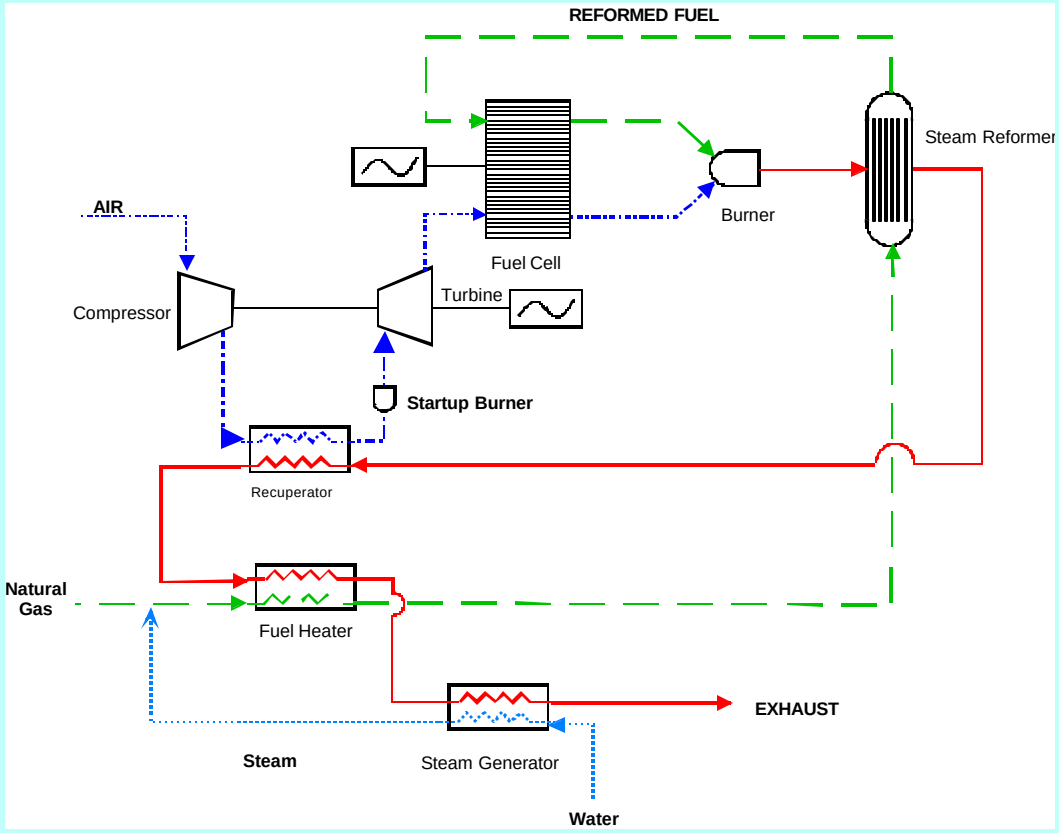
Fuel added to combustor to raise the turbine inlet temperature

Power Split FC/GT 55/45

Siemens Westinghouse/Caterpillar Results

- 2 x 10 MWe-Class PSOFC/ATS-GT Power Systems
- System Efficiency Near 60%
- Low COE Relative to Conventional Power Generation
- NOx Similar to Solar Mercury 50

Recuperated Combined Cycle (McDermott)



Notes

Atmospheric Fuel Cell

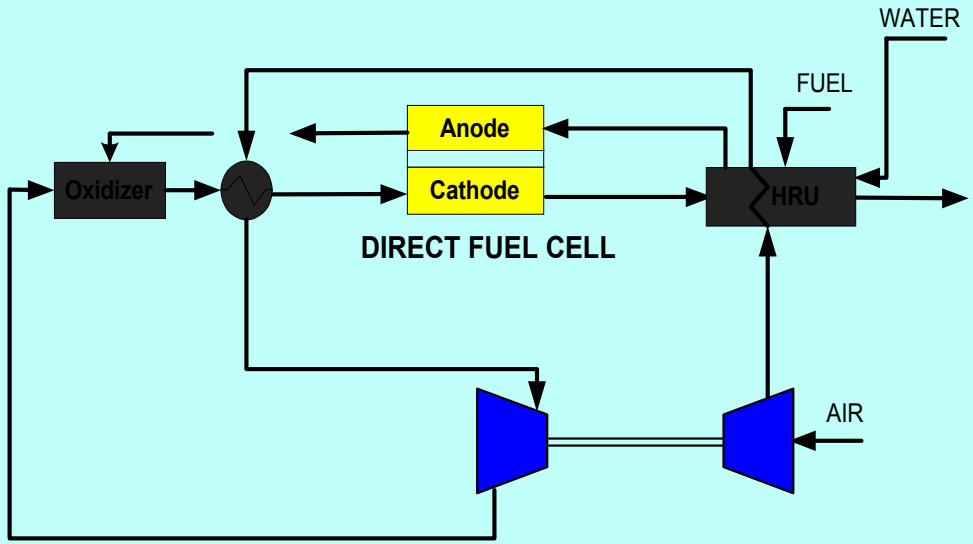
McDermott/SOFC/NREC Results

- COE is Comparable to Present-Day Alternatives
- 70% Efficiency Possible
- Economics May Favor Lower Efficiency Systems

HIGH EFFICIENCY HYBRID DFC / TURBINE POWER PLANT

(ERC)

Compressed Air is Heated with Fuel Cell Waste Heat, Expanded, and then Used as the Fuel Cell Oxidant



Notes

Atmospheric Fuel Cell

- *Efficiencies of more than 70% are possible*
- *Potential to Significantly Lower $/kW Cost*

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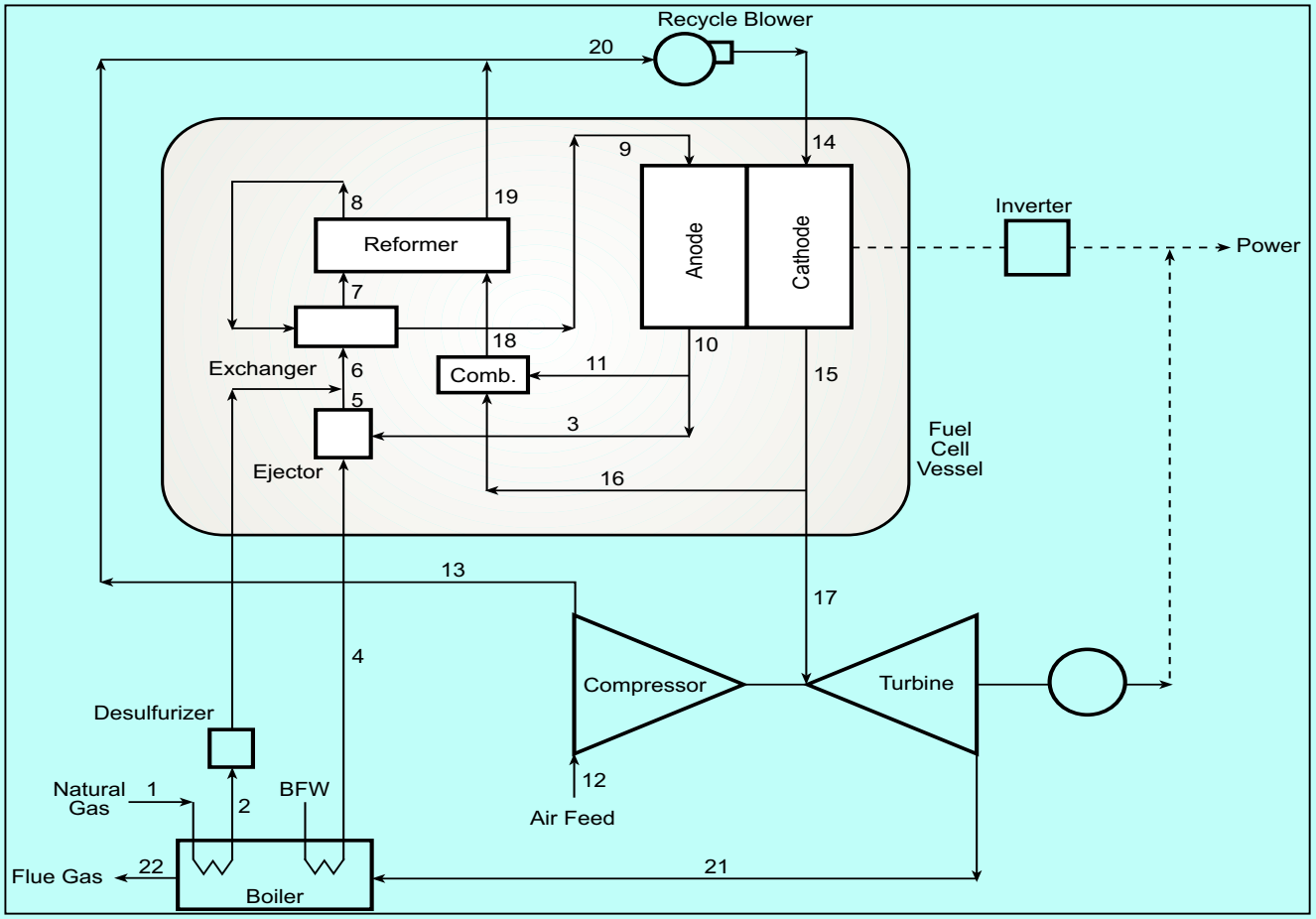
Energy Research Corp/Allison Results

- COE is Comparable to Present-Day Alternatives
- 65% Efficiency With Off-The-Shelf Turbomachinery
- ~72% With Cycle-Specific Turbomachinery
- NOx Less Than 1 ppm

M-C Power Hybrid System



Notes

6 ATM

M-C Power Results

- 70% Efficient
- NOx Less Than 1 ppm
- COE is Comparable to Present-Day Alternatives

Issues

- **Tradeoffs**
  - Cost vs. Efficiency vs. Emissions
- **Fuel Cell - Turbine Integration**
- **Turbine Optimization**