Turbines for Fuel Cell Hybrid Systems

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Presentation Outline

UCI-Advanced Power and Energy Program (APEP)

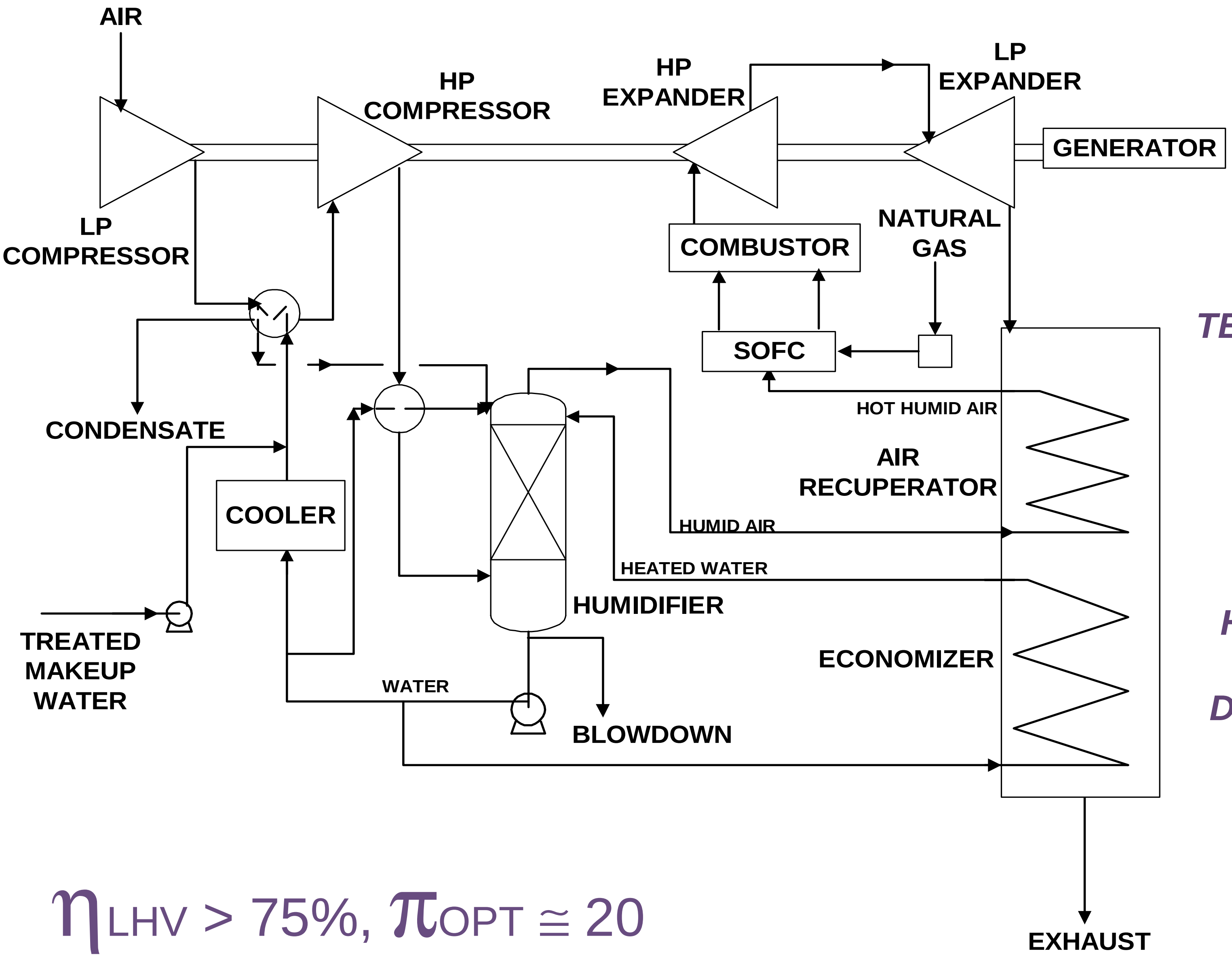
- Vision 21 Systems Development and Analyses
- Hybrid Fuel Cell Dynamic Systems Analyses
- SOFC-GT Hybrid Integration and Testing

Some Recent Developments

Technical Issues for Hybrid Systems

- Program Results and Findings
- DOE/UN Hybrid Conference Stakeholder Input

Vision 21 Systems Development & Analyses



ADVANCED GAS TURBINE TECHNOLOGY – HAT REQUIRED

ADVANCED FUEL CELL TECHNOLOGY – HIGH PRESSURE & HIGH CURRENT DENSITY REQUIRED

$\eta_{LHV} > 75\%$, $\pi_{OPT} \cong 20$

Vision 21 Systems Development & Analyses

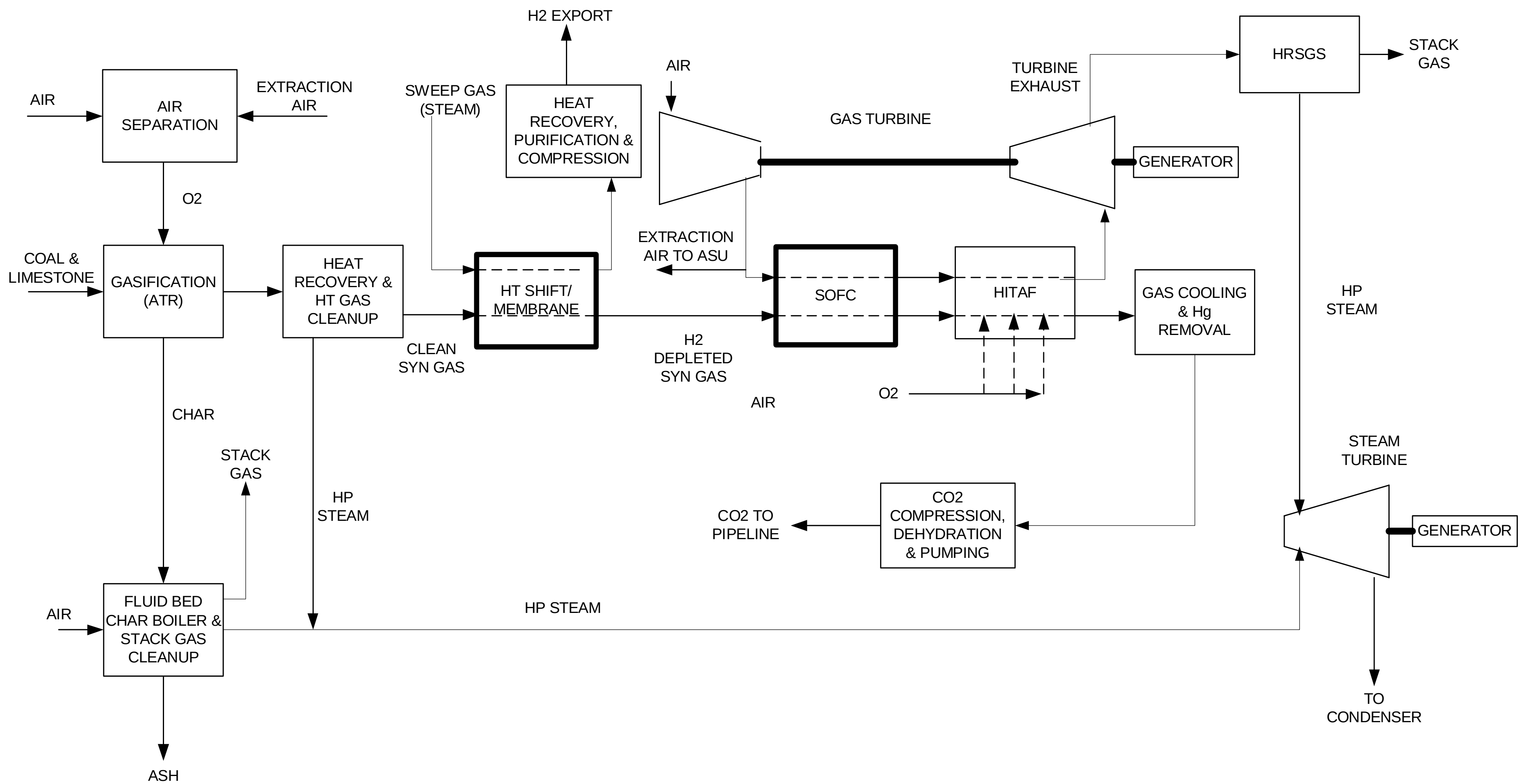
Sample Natural Gas Cases

	HP SOFC + IC GT HYBRID	HP SOFC + HAT HYBRID	ATM P MCFC + IC GT HYBRID	O_2 BREATHING HP SOFC + HAT HYBRID	ADV RANKINE (H_2/O_2 COMBUSTION)
TOTAL POWER BY FUEL CELL (PERCENT)	72	68	74	68	-
TOTAL POWER BY GAS TURBINE (PERCENT)	28	32	26	32	100
THERMAL EFFICIENCY (PERCENT LHV)	>75	>75	70	>60	52
SPECIFIC POWER (KW/LB/S)	985	1000	830	800	-
PRESSURE RATIO	50	20	25	20	3200

CO_2 RECOVERY

Vision 21 Systems Development & Analyses

Coal Cases – FutureGen Example #1



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Hybrid Systems Dynamic Modeling

MATLAB and Simulink™ Modular Approach:

Simulation modules for fuel cells and system components

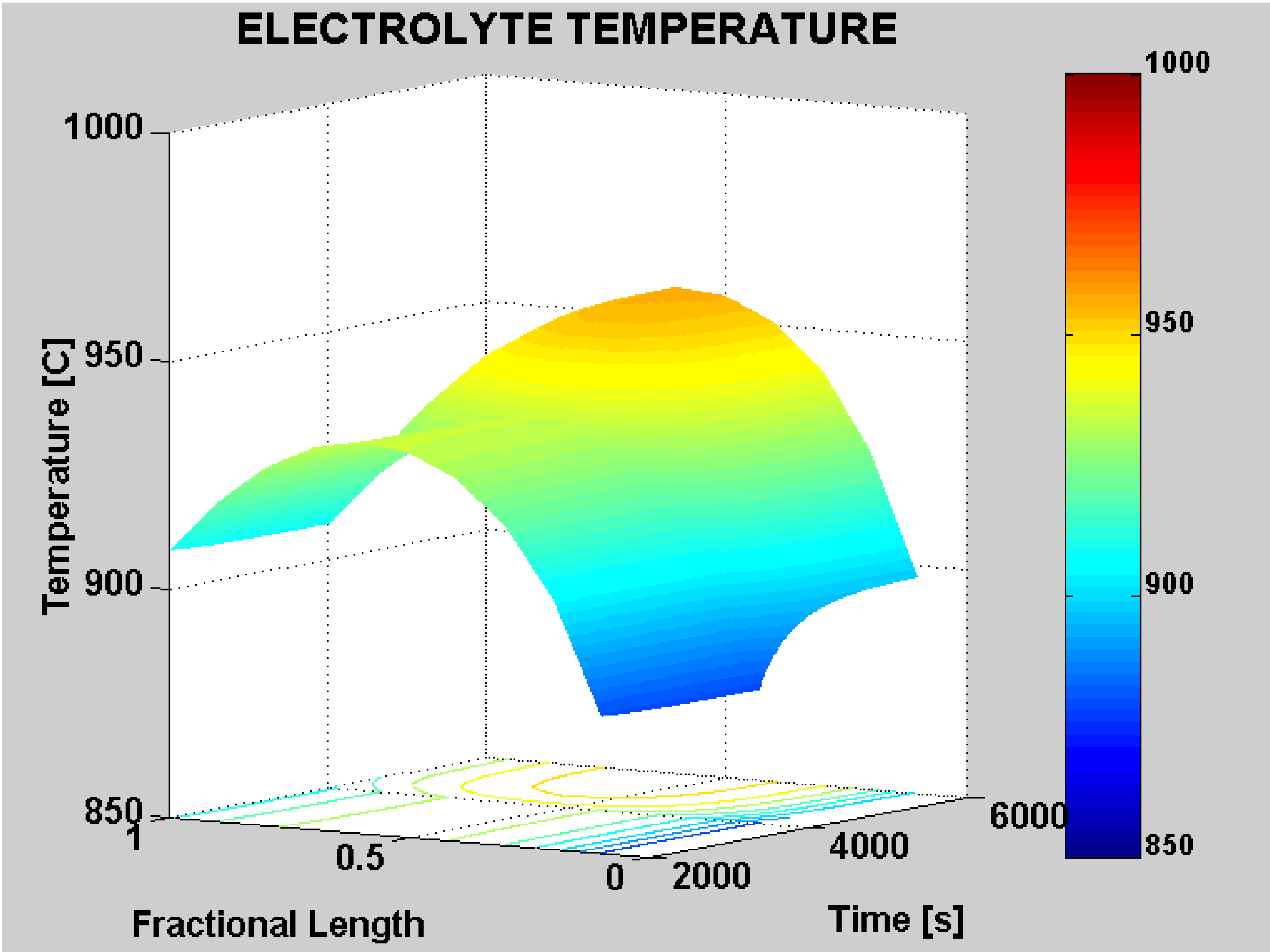
- Tubular SOFC
- MCFC
- Planar SOFC
- Reformer module
- Gas turbine module (compressor and turbine sub-modules)
- Combustor module
- Catalytic oxidizer module
- Heat exchanger module
- Humidifier module
- Condenser module
- Pumps, valves, regulators, plumbing, and other balance of plant (BOP)

DoD Fuel Cell Program Grant #: 482517-25536

California Energy Commission Contract #: 500-99-028

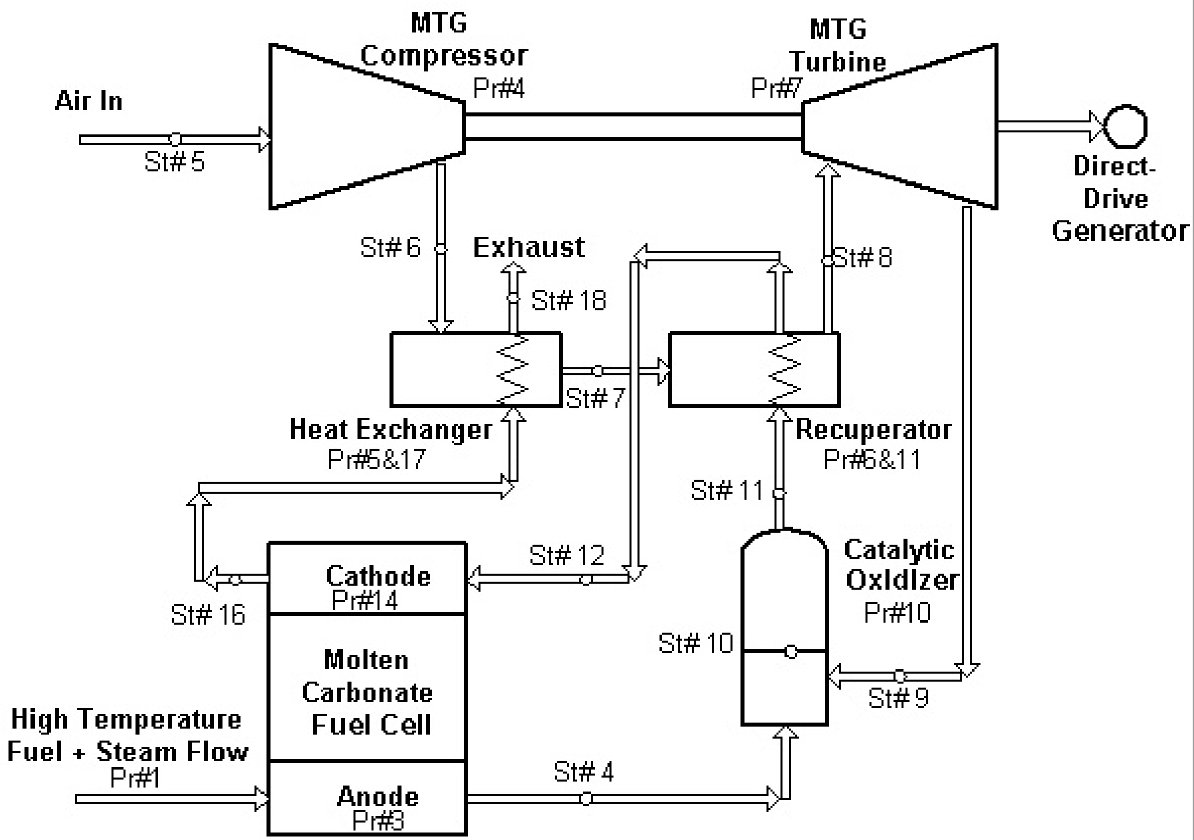
Hybrid Systems Dynamic Modeling

SAMPLE TSOFC OUTPUTS: 10% LOAD INCREASE



Hybrid Systems Dynamic Modeling

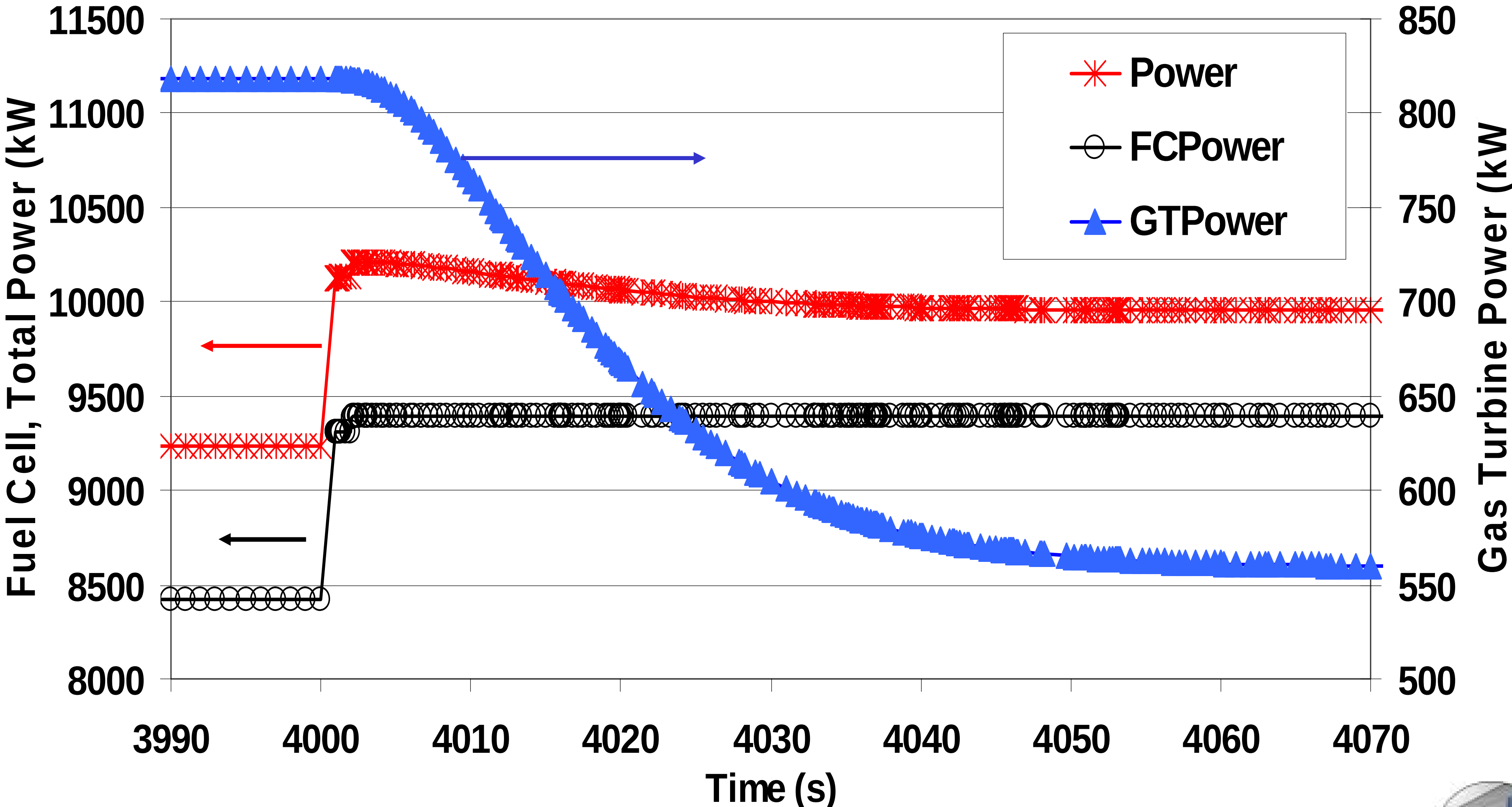
GENERIC – BASED UPON FUELCELL ENERGY DIRECT FUEL CELL HYBRID



State No.	State Name
4	Anode Exit/Catalytic Oxidizer Entrance
5	Ambient Air Inlet
6	Compressor Exit to Heat Exchanger
7	Exhaust Recuperator Exit—Hot Side
8	Turbine Inlet
9	Turbine Exit
10	Combustor Inlet, Fuel/Air Mix
11	Combustor Exit
12	Cathode Inlet
16	Cathode Outlet
18	Heat Exchanger Exhaust

Hybrid Systems Dynamic Modeling

NFCRC Model – 10% Power Demand Increase from MCFC



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SOFC-GT Integration and Testing

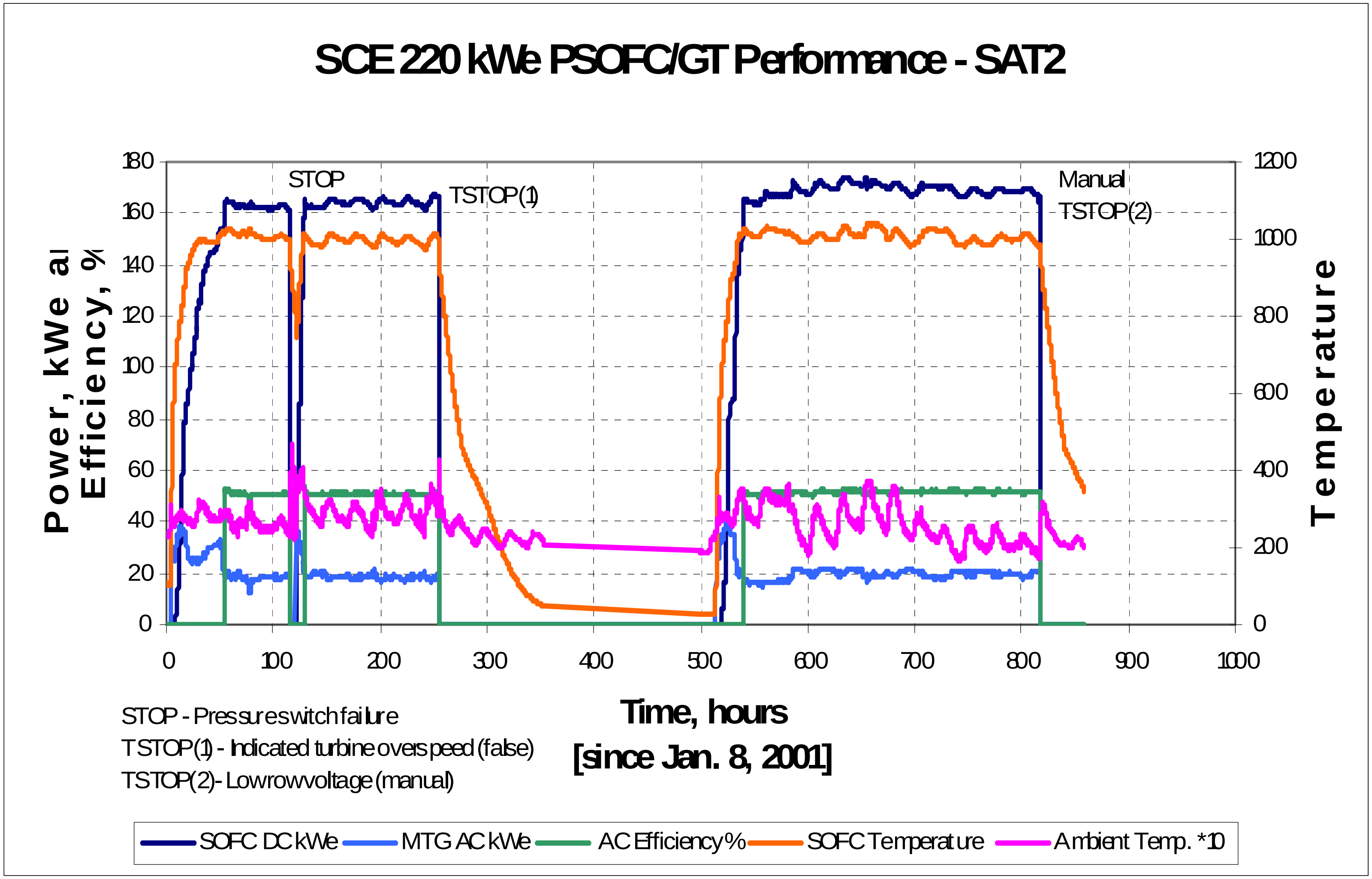
220 kW HYBRID SYSTEM:

Southern California Edison, Siemens-Westinghouse - SOFC with IRES micro-turbine

Over 3000 hours of operation

SOFC-GT Integration and Testing

220 kW Hybrid System – Example Results



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SOME RECENT DEVELOPMENTS

FuelCell Energy–Direct FuelCell™/Turbine Hybrid System

- **Objectives**
  - **Design a 40 MW FC/T hybrid**
  - **Test sub-MW prototypes**
- **280 kW system completed 6,740 hrs. of testing**
  - **Efficiency of 52%**
  - **NOx & SOx below 0.1 ppm**
- **Future Plans**
  - **Fully integrated hybrid system w/ 60 kW Capstone for a demo in Montana**
  - **40 MW power plant design**

SOME RECENT DEVELOPMENTS

Siemens Westinghouse – TSOFC–Gas Turbine Hybrid System

- **Objectives:**
  - Demonstrate technical feasibility of PSOFC-GT
  - Demonstrate high efficiency (45 – 60 %) of SOFC hybrids
- **World's first SOFC Hybrid**
  - 3000 hrs. of operation
  - Pressurized operation
  - 53 % efficiency
- **Future Plans**
  - Commercialize atmospheric pressure CHP250 systems
  - Optimize GT & SOFC configuration for commercialization by 2010

SOME RECENT DEVELOPMENTS

Solid State Energy Conversion Alliance:

SECA Phase III

- **Power Rating Net = 3-10 kW**
- **Cost = $400 / kW**
- **Efficiency (AC or DC/LHV)**
  - **30 - 50% [APU]**
  - **40 - 60% [Stationary]**
- **Steady state testing (>1500 hours)**
  - **95% availability**
  - **Power <0.1% degradation/500 hours**
- **Transient testing (>100 cycles defined by application)**
  - **Power < 1% degradation after 100 cycles**
- **Design Lifetime = 5,000 Hours (APU), 40,000 Hours (Stationary)**
- **Maintenance Interval > 1,000 Hours**
- **Fuels**
  - **Natural Gas**
  - **Gasoline**
  - **Diesel**

After: Mark Williams, U.S. DOE, 2002

SOME RECENT DEVELOPMENTS

Six SECA Industrial Teams

SIEMENS Westinghouse

General Electric Company

FuelCell Energy, Inc.

DELPHI
Driving Tomorrow's Technology

Battelle

Cummins Power Generation

SOFCo

Accu:metrics

GENERAL DYNAMICS
C4 Systems

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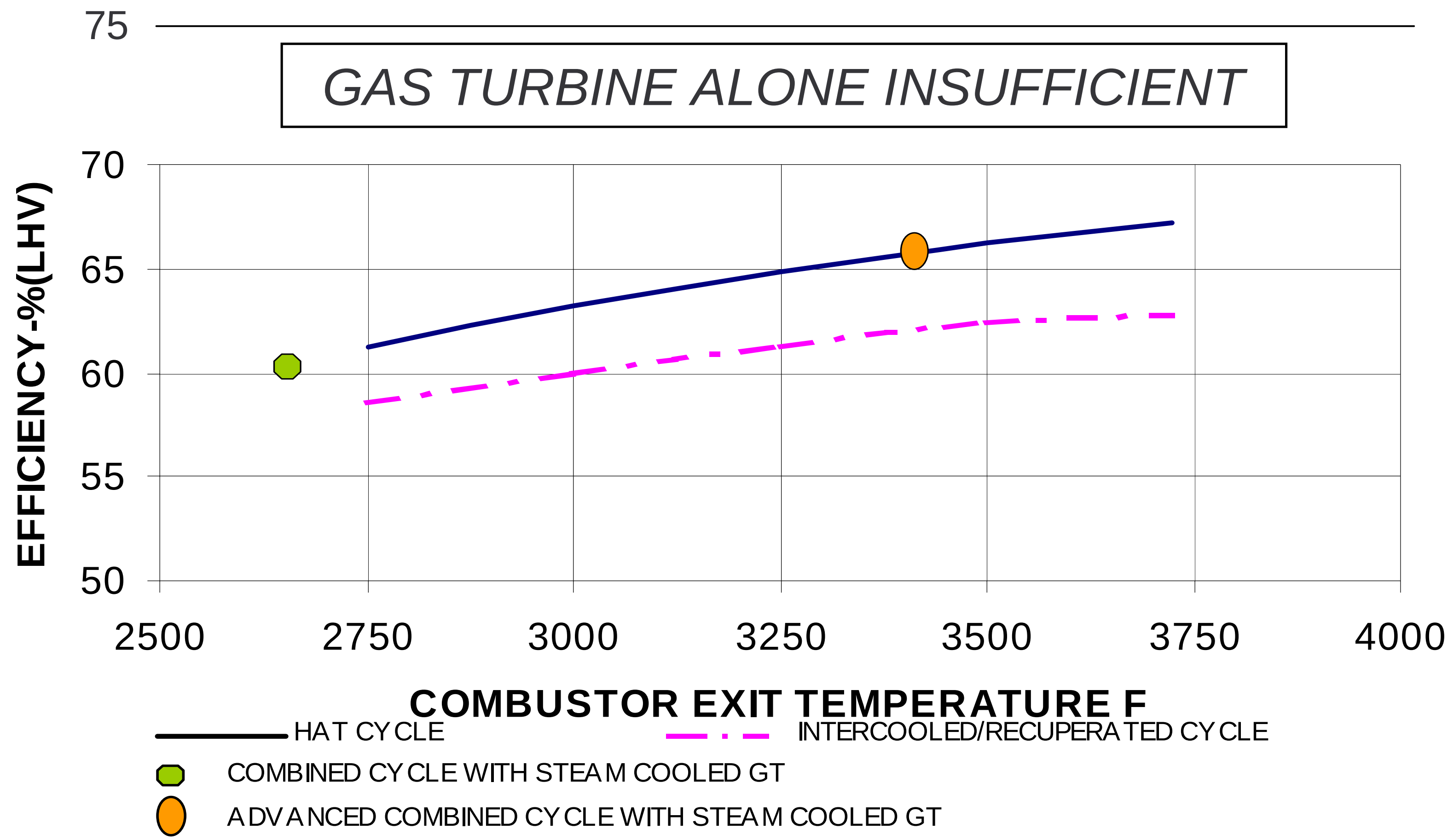
Program Results and Findings

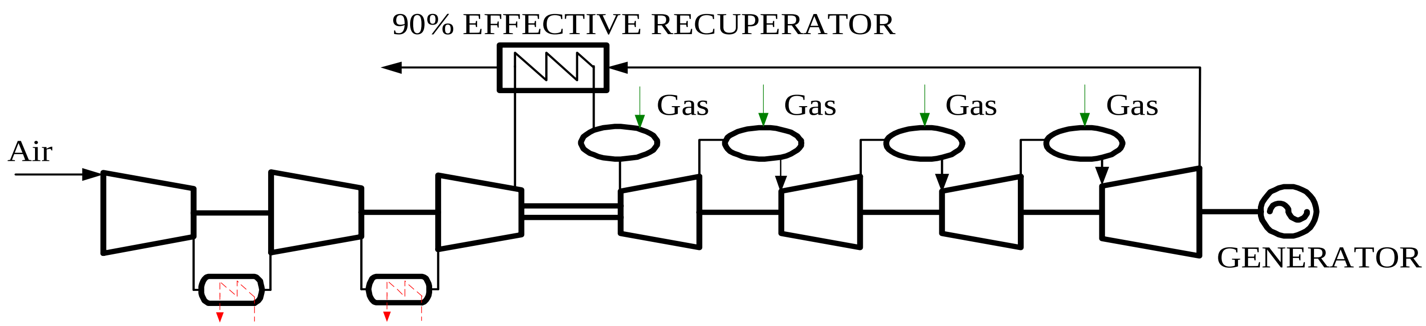
Vision 21 Systems Analyses



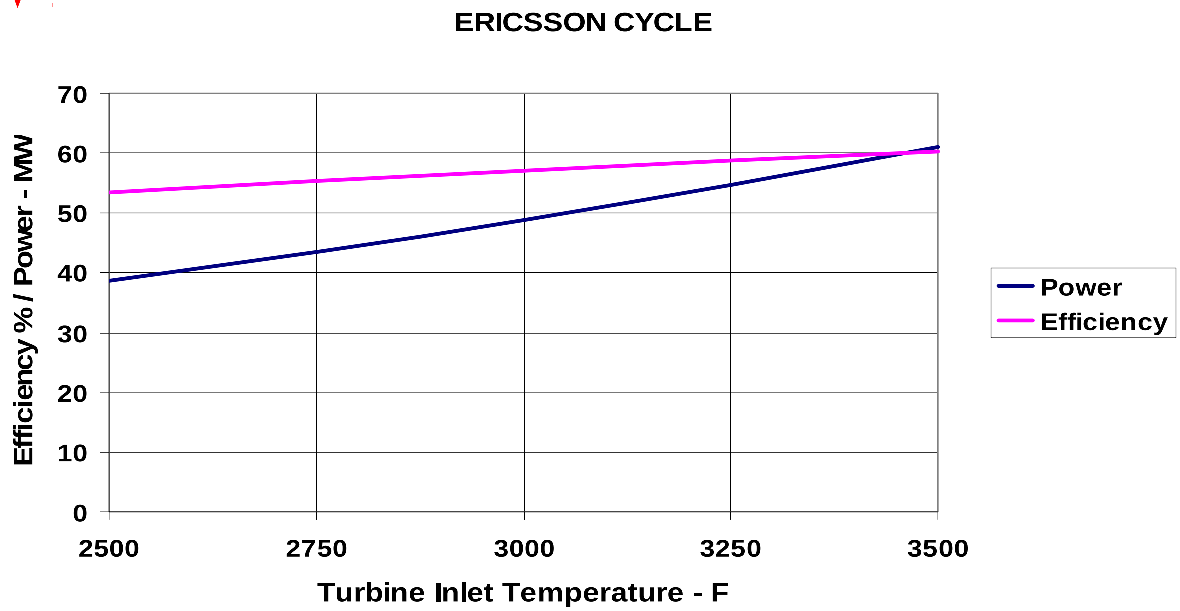
Program Results and Findings

Vision 21 Systems Analyses

ERICSSON CYCLE η_{LHV} < 60%, $\pi \cong 100$



1 - ISO Air
2 - 67 psig
3 - 65 psig/90 F
4 - 303 psig
5 - 293.6 psig/90F
6 - 1364.5 psig
7 - 1241.7 psig 2500F/ 3000F/3500F



Technical challenges (1/6)

FUEL CELL

High Pressure SOFCs

- Pressure of 20 bar desired

Higher current density materials (w/o extensive use of exotic materials)

- To limit physical size of 200 MW fuel cells
- To limit stack modules & minimize high temperature piping/manifolding
- Fuel cell cost reduction

Separate anode & cathode exhausts from SOFC for zero CO_2 emission plants

Technical challenges (2/6)

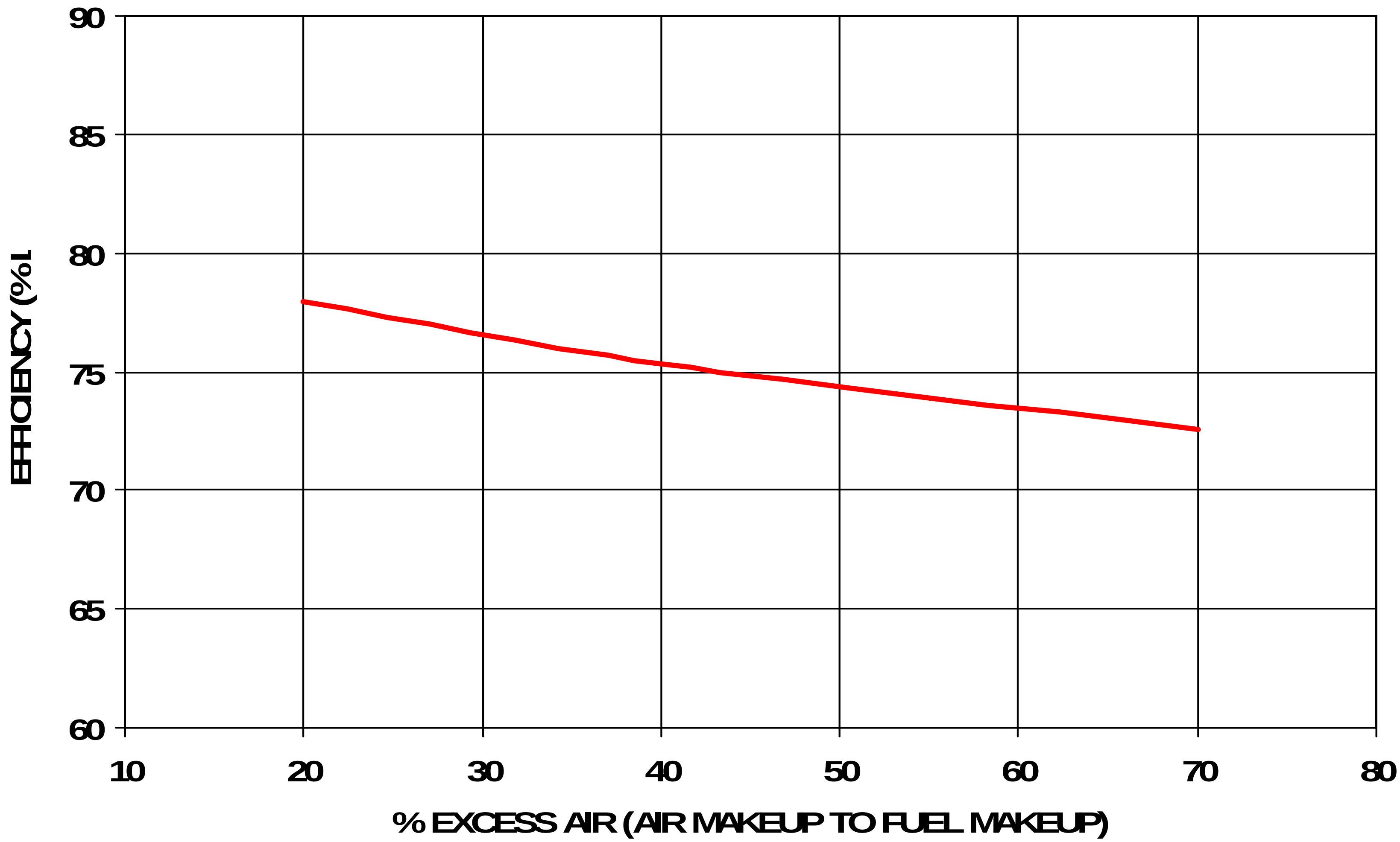
FUEL CELL – HEAT MANAGEMENT

Near stoichiometric air/fuel ratio required in fuel cell for high efficiency if GT development limited to nonreheat

- Management of heat generated within cells challenging
- Internal reforming required
- Water vapor addition to fuel/air (HAT) assists as heat sink
- And increases motive fluid in turbine (water introduced efficiently, humidifier recovers IT heat)
- But decreases partial pressure of reactants, increases cell polarizations
- Balance between two required

Program Results and Findings

Natural gas SOFC/HAT efficiency vs. excess air



Technical challenges (2/6)

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Technical challenges (3/6)

FUEL CELL - SYN GAS CONTAMINANT TOLERANCE

Sulfur species

Alkalies

Chlorides

NH_3 and HCN

Technical challenges (4/6)

GAS TURBINES

Large (~90 MW) GTs Required

- Recuperative type
- Low firing temperature

Intercooler desirable

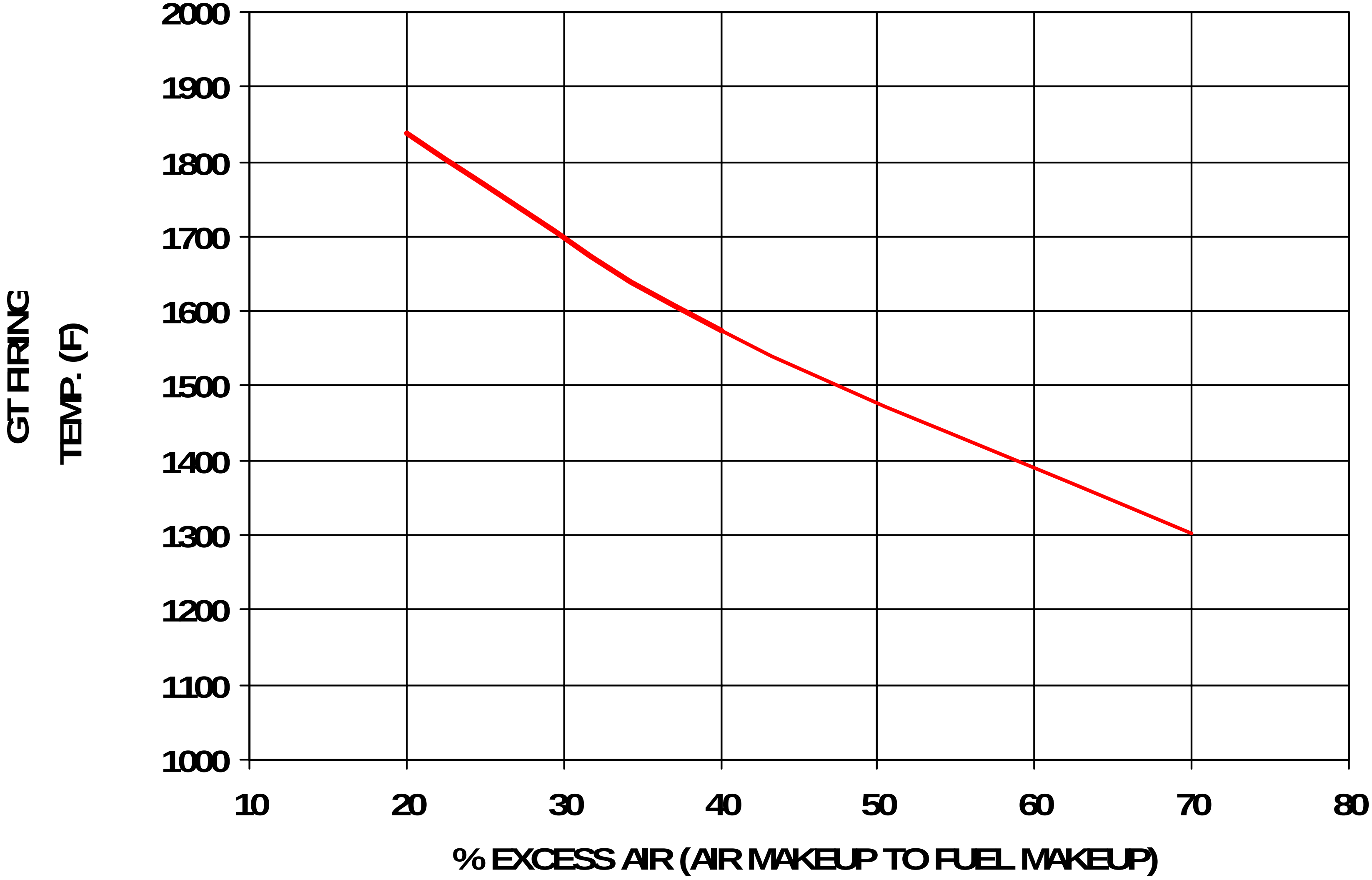
- High specific power
- Enhance efficiency (for natural gas SOFC/HAT & potentially for coal based)

Large GTs with combustors accepting hot & depleted fuel & air required (when GT combustor used)

Large GTs with oil free bearings

Program Results and Findings

Natural gas SOFC/HAT GT firing temp. vs. excess air



Technical challenges (4/6)

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Large GTs with oil free bearings

Technical challenges (5/6)

GASIFICATION AND CLEAN-UP

Ionic membrane air separation

ATR carbon conversion

HT gas cleanup

HT shift/membrane separation of H_2

HITAF

Technical challenges (6/6)

SYSTEMS INTEGRATION AND CONTROL

Detailed economic and market analyses

Detailed steady state and dynamic performance analyses

BOP simplification and reliability advancement

FCT hybrid systems (components, integration, controls) conceptualization, development, and testing

Specification and design of control systems

Power island module (FCT components, integration, controls) advancement for coal and natural gas

Summary

Hybrid Fuel Cell Gas Turbine Systems have great promise

- Ultra-high efficiency (not matched by either technology alone)
- Ultra-low emissions
- Amenability to sequestration and value-added product production

Concept has been proven in two system prototypes to-date

- FuelCell Energy – DFCT – over 6,000 hrs, 52%
- Siemens Westinghouse – SOFC-GT – over 3,000 hrs, 53%

Analyses show potential and reveal challenges

Challenges can be overcome with good approach and significant attention/investment

Gas turbine systems advancement focused on hybrid FC systems will significantly contribute