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SOFC Program Review

10th Annual SECA Workshop

Pittsburgh, PA

14 July 2009

David Brengel - Project Manager

Overview

- UTC Power is a world leader in developing and producing fuel cells that generate energy for buildings and for transportation, space and defense applications

- Part of the $58 billion United Technologies Corporation

R&D facility located in South Windsor, CT

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Overview

- Capacity to annually manufacture 40 MW of PAFC stacks for the stationary market
- Capacity to annually manufacture 24 MW of PEM stacks for the transportation market

Manufacturing located in adjacent facility

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Stationary Market

- The PureCell® System Model 400 produces 400 kilowatts of assured power, plus about 1,700,000 Btu/hr of heat for combined heat and power (CHP) applications using four 100 kW phosphoric acid stacks
- Design Lifetime of 80,000 hours
- First shipment to a customer on 29 June 2009

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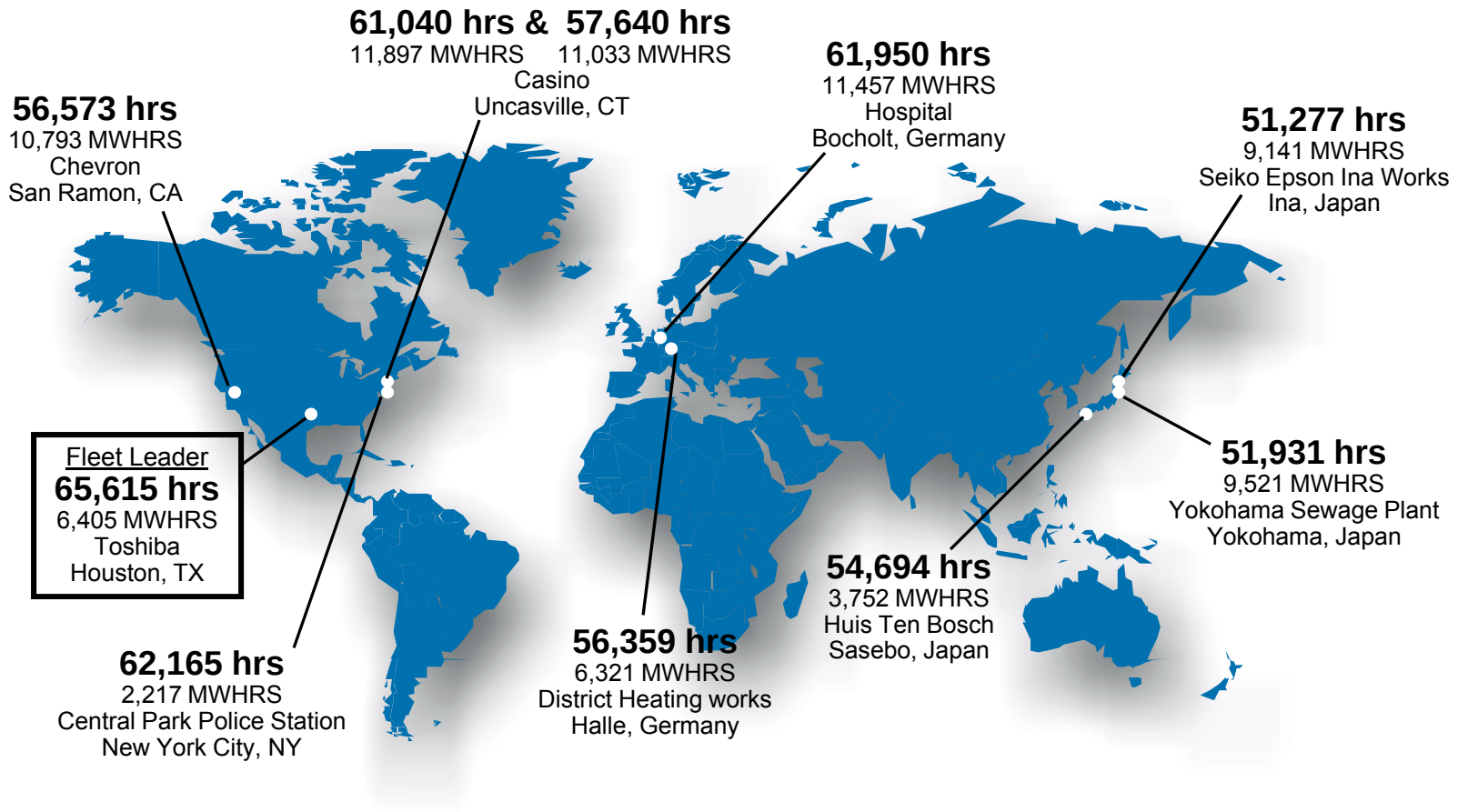
Stationary Market

Successful track record around the world - 200 kW systems



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Transportation Market

- The PureMotion® System Model 120 produces 120 kW for zero-emission hybrid-electric fuel cell powered buses

CT Transit bus

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Transportation Market

- UTC Power has partnered with Hyundai-Kia Motor Company, Chevron Technology Ventures, Nissan, BMW and the U.S. Department of Energy, to develop fuel cell technology for cars

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Test Stands

- UTC Power has extensive experience designing and operating large test stands

- Currently operating
  - Two PAFC test stands ≥100 kW
  - Eight PEM test stands ≥ 75 kW

100 kW PAFC test stand with CSA in background

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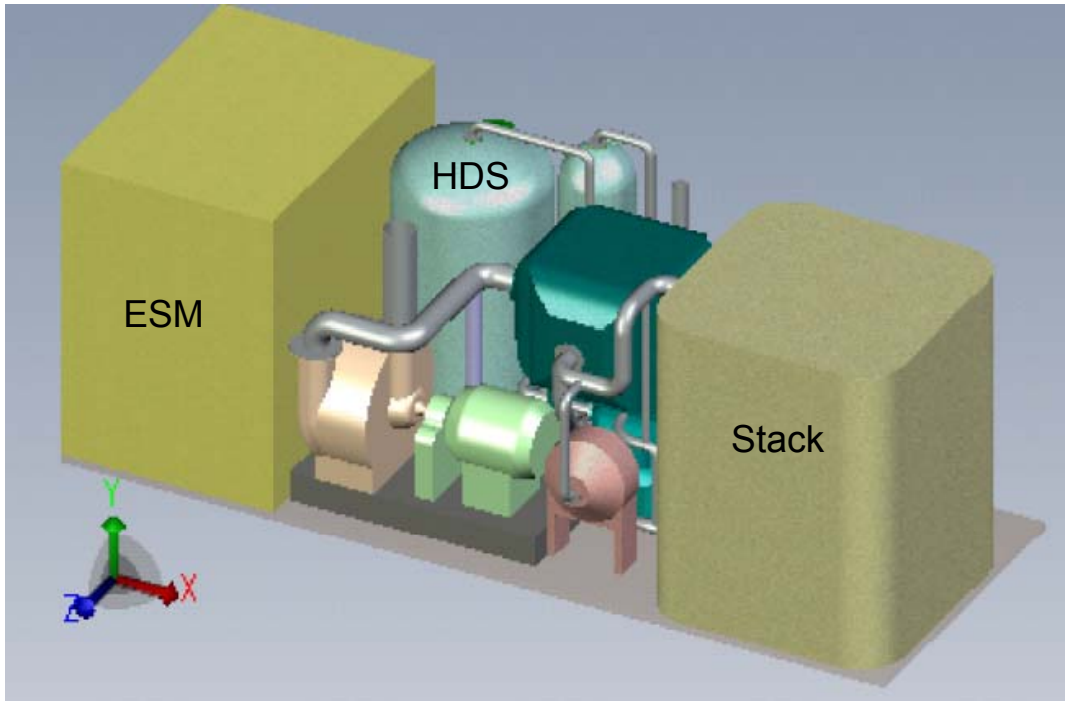
Positive Attributes of an SOFC Power Plant

- High electrical efficiency
- High power density
- Simplified unit operations
- Potentially lower cost



Solid model rendering of 400 kW power plant

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System Concepts & Stack Design Integration

Outline

- Design of a 250-1000 kW Ambient Pressure Power Module
- Design of 5 MW Ambient Pressure POC
- Baseline IGFC System Concept Development
- System Cost Analysis

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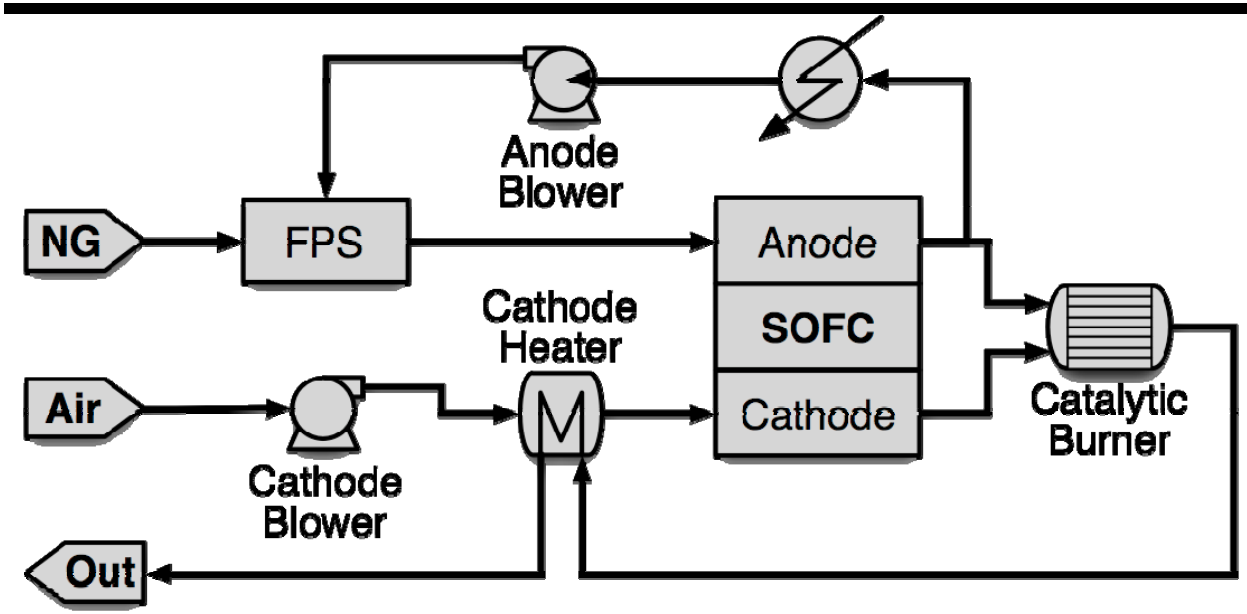
250-1000 kW Power Module



Design Point

- Net AC power = 400 kW
- Electric efficiency >55%
- Cell voltage = 800 mV
- Stack inlet = 700 °C
- Stack outlet = 825 °C

- Fuel Processing System (FPS)
  - Fuel clean-up based on Hydrodesulphurization (HDS) technology
  - Fuel processing via catalytic steam reforming
- Anode recycle
  - High system efficiency and fuel utilization at moderate per-pass utilizations
  - Water for steam reforming and hydrogen for HDS

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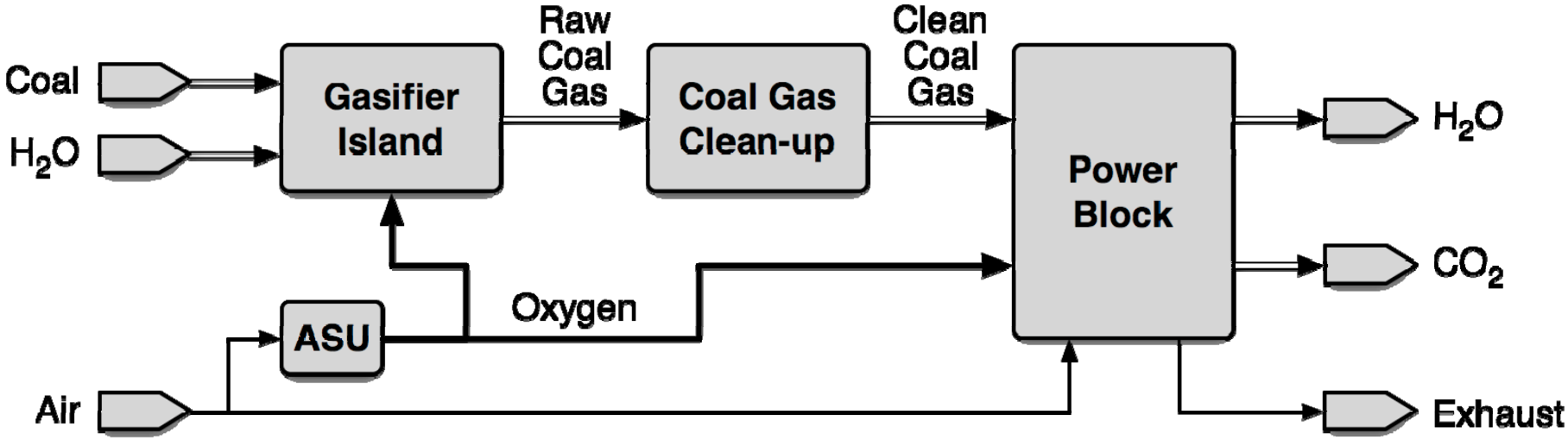
Baseline IGFC Overview



- Catalytic gasification: High cold gas efficiency & methane content
- Oxygen generation via cryogenic distillation (ASU)
- Sulphur removal via Selexol or warm-gas clean-up
- CO_2 separation via oxy-combustion

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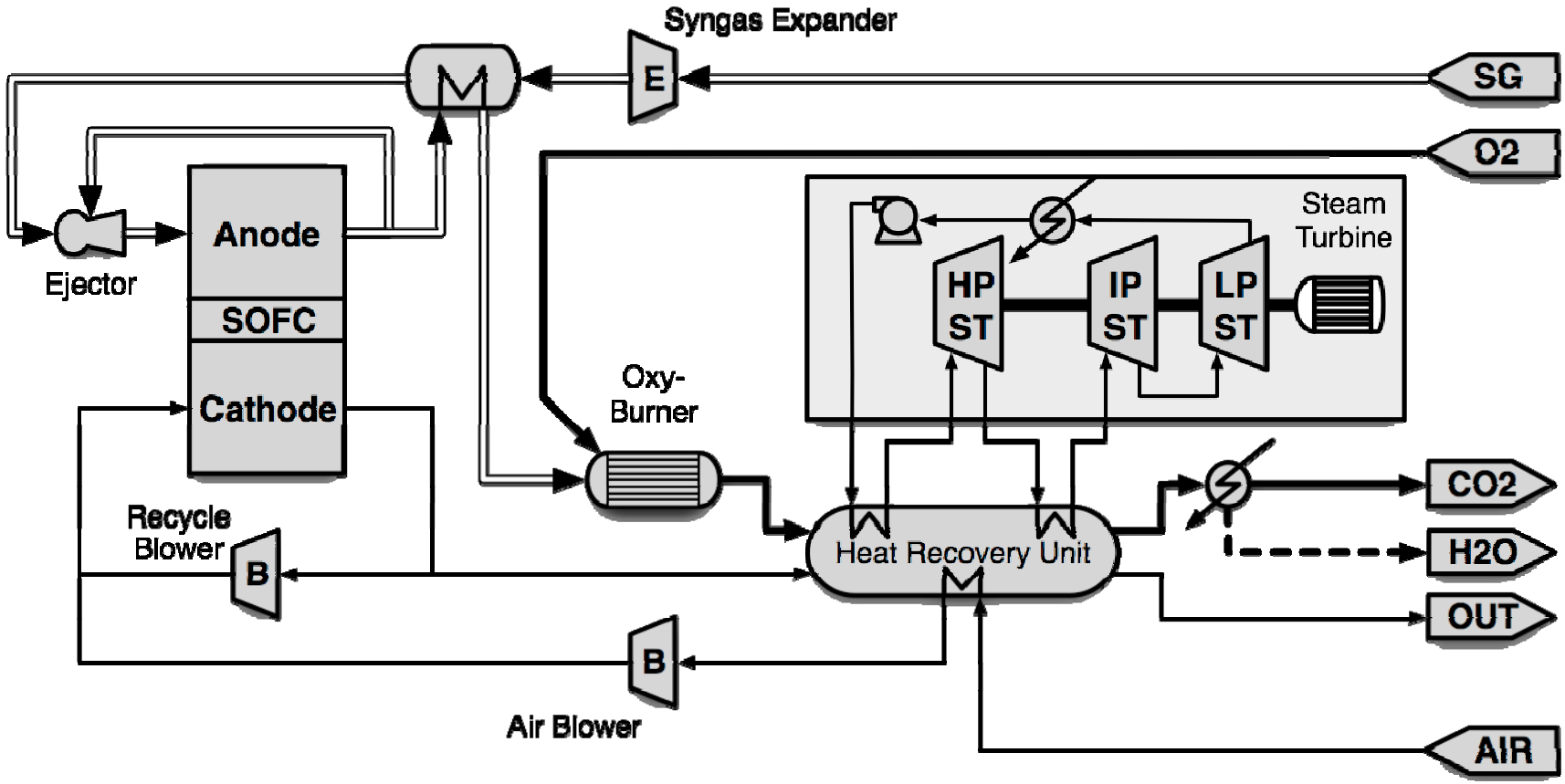
IGFC Power Block Design

- Systems of increasing sophistication and efficiency are being developed
  - Atmospheric SOFC with Steam Turbine Cycle
  - Atmospheric SOFC with Gas and Steam Turbine Cycle
  - Pressurized SOFC with Gas and Steam Turbine Cycle
- Steam cycle with reheat: [1800 psig ,1050°F, 1050°F]
- Gas turbine: Modified P&W FT-8 at 5 atm
- Heat recovery unit maximizes re-use of waste heat from cathode exhaust and oxyburner
  - Steam generator, re-heater
  - Cathode pre-heat
  - Indirectly heated gas turbine

Atmospheric SOFC/ST



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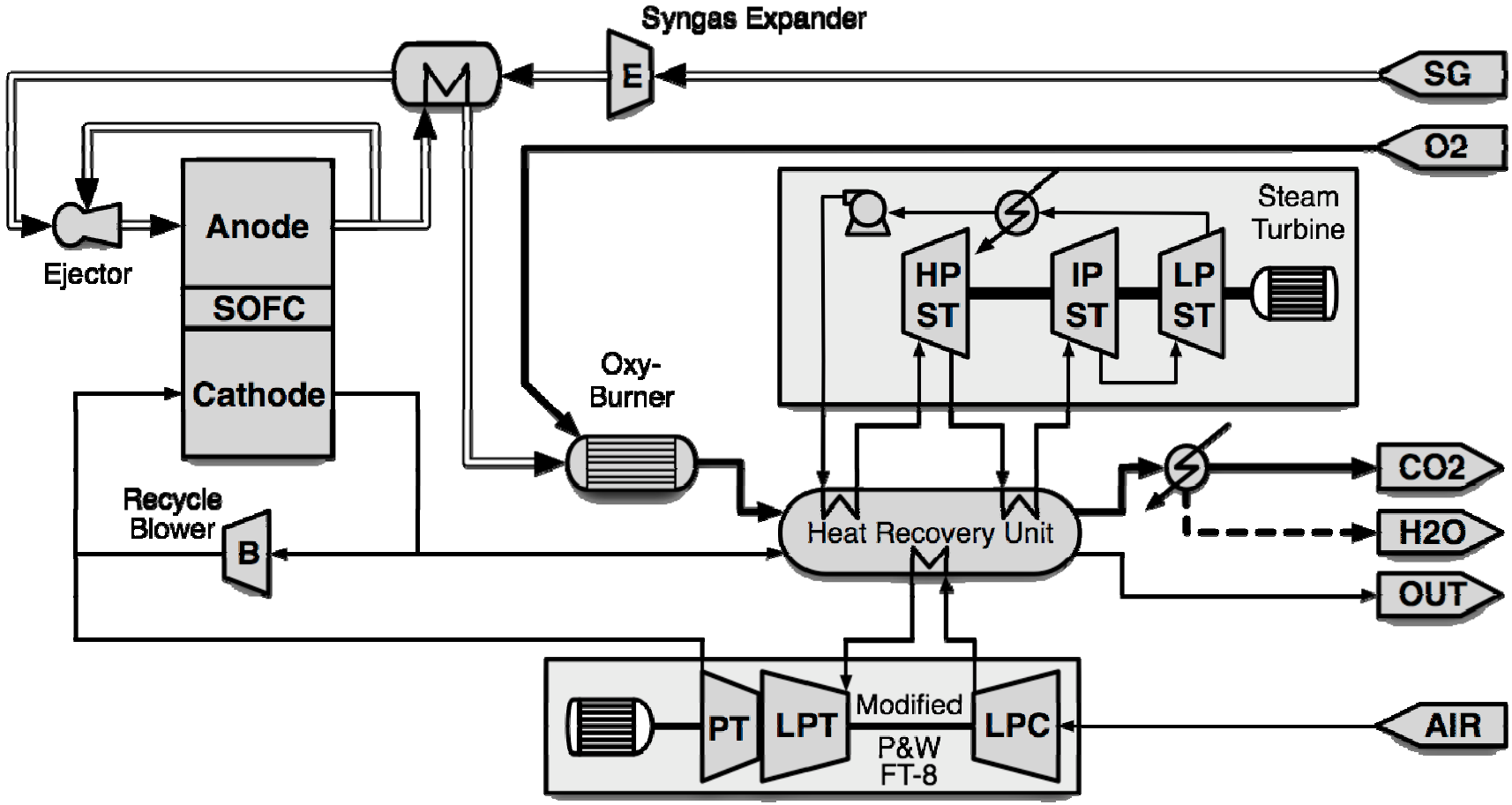
Atmospheric SOFC/GT/ST



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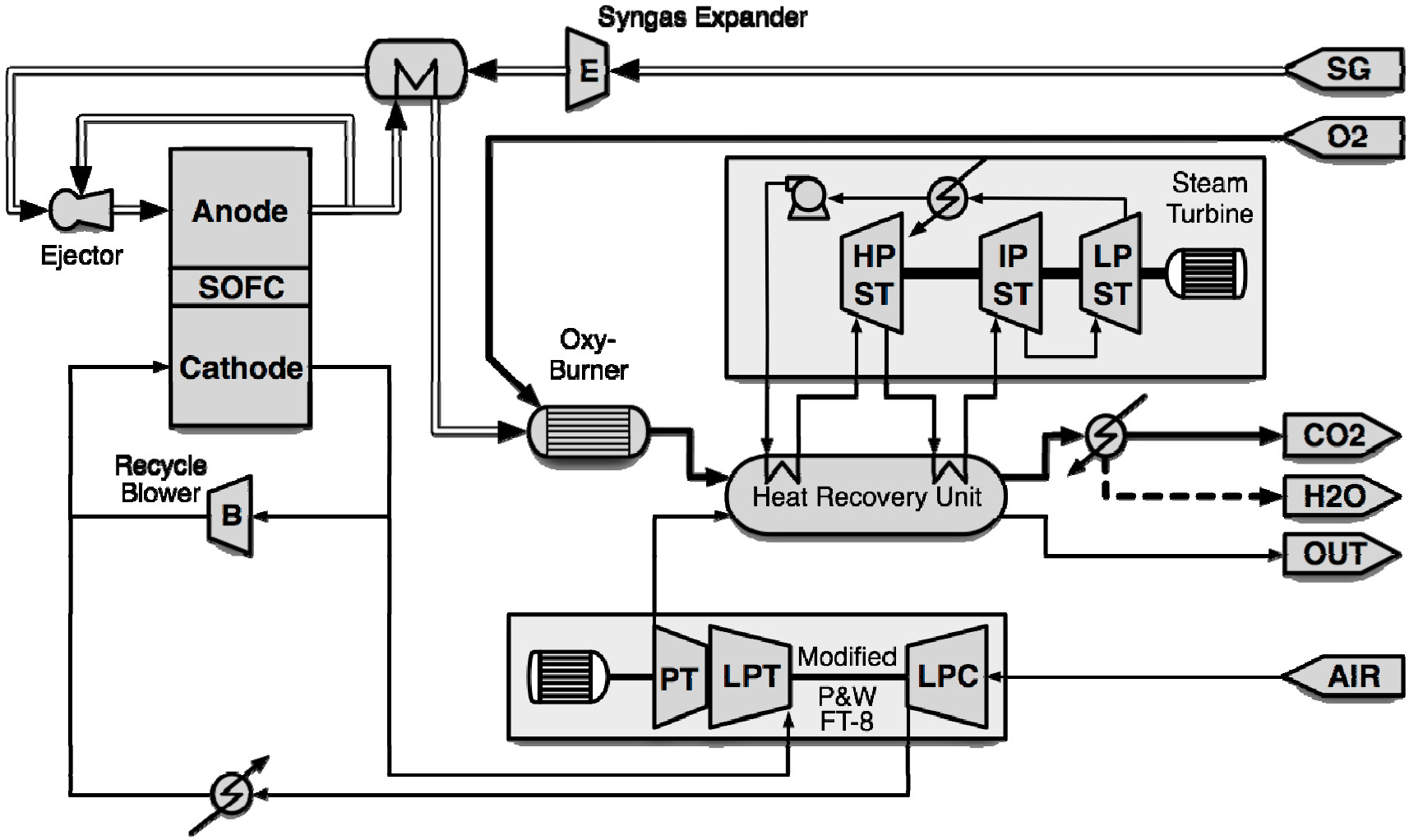
Pressurized SOFC/GT/ST



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IGFC Performance Summary (Preliminary)

	Atmospheric		Pressurized
	SOFC/ST	SOFC/GT/ST	SOFC/GT/ST
Net Efficiency* [%, HHV]	**45.3**	**50.6**	**51.5**
Net AC Power [MW]	**166.5**	**186.1**	**189.0**
SOFC DC [% gross]	85.4	79.4	79.9
Steam Cycle [% gross]	14.6	10.3	9.9
Gas Turbine [% gross]		10.3	10.2

* Efficiency includes CO_2 separation/compression parasitics

Model Assumptions

- Cold gas efficiency = 85%
- Steam turbine efficiency = 30%
- Gas turbine efficiency = 85%
- Inverter efficiency = 96%

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