Integrated Gasification Fuel Cell (IGFC) Systems

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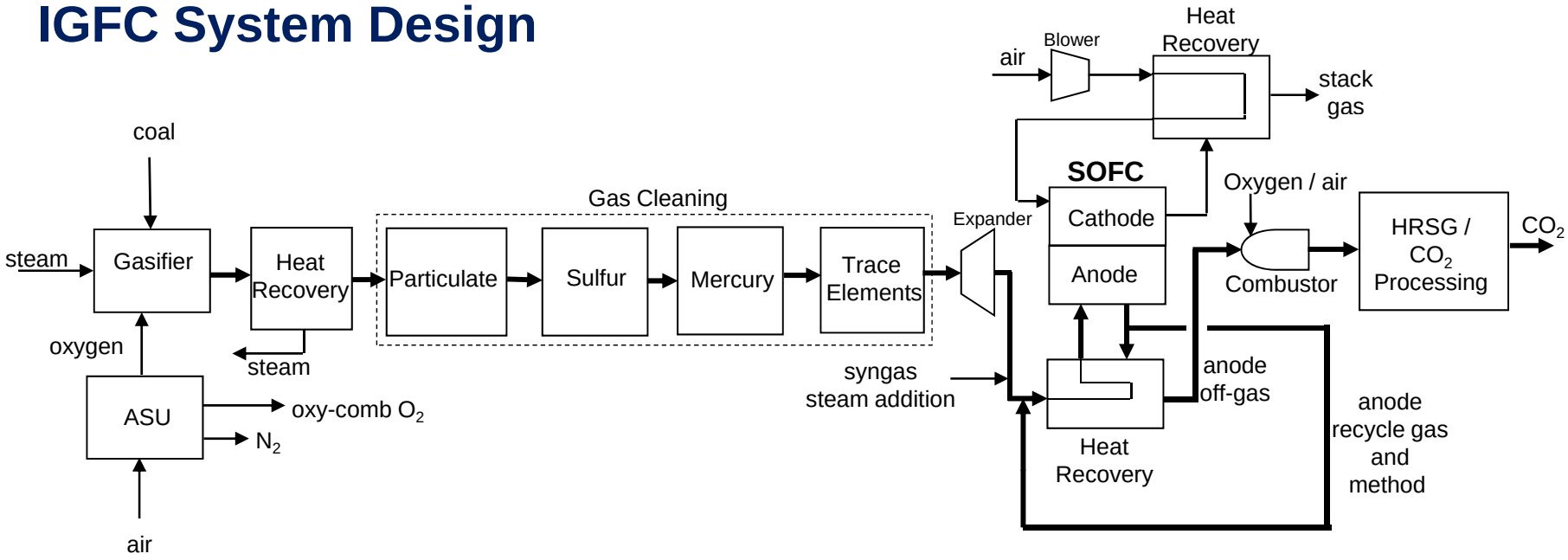
Questions

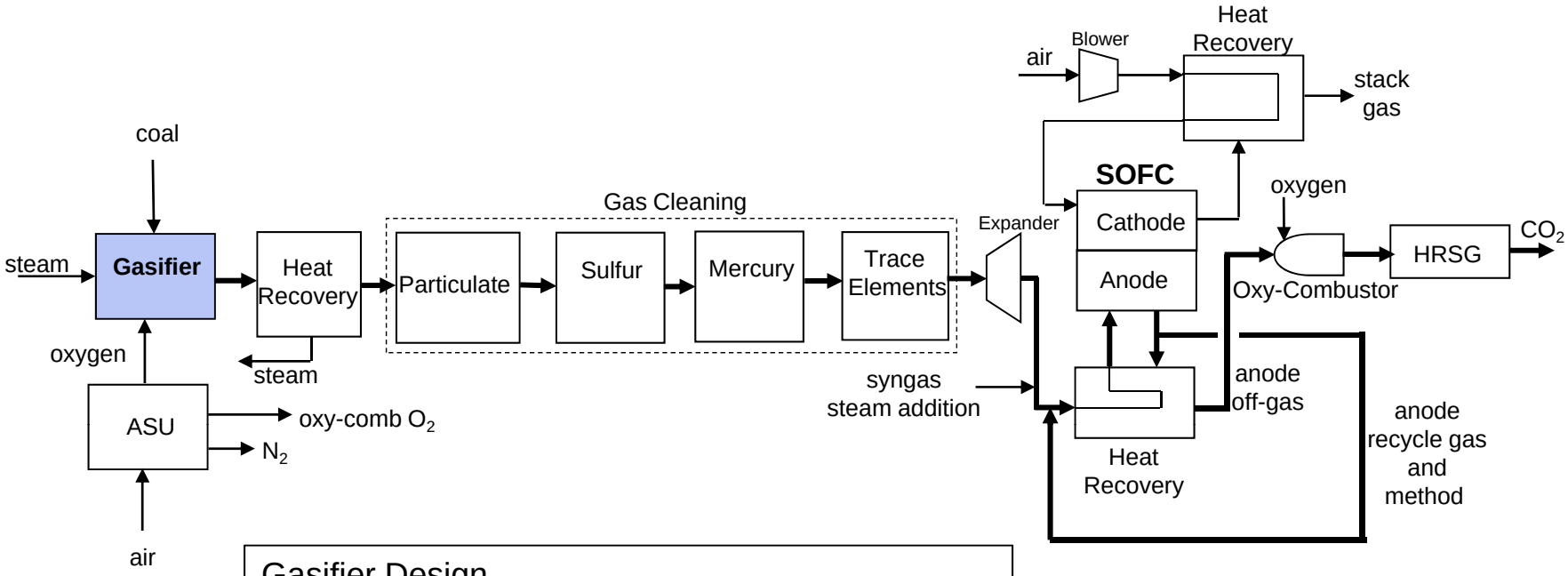
- What is the Potential for IGFC Systems?
  - System Efficiency
  - Capital Cost
  - Cost of Electricity
  - Water Use
- What are the significant
  - Design Parameters
  - Operating Conditions

IGFC System Design



System Parameter	Design and Operating Parameter Assumptions
Feed	Coal, Coal + Methanation, Coal + NG injection, NG
SOFC Operating Conditions	Pressure (Atm, Elevated), Temperature, Fuel Utilization, Voltage
SOFC System Design	Anode Gas Recycle, Cathode Gas Recycle, Methods of Recycle
Gasifier	'Commercial', Catalytic
Gas Cleaning	Dry Gas Cleaning, Humid Gas Cleaning
Anode Off-Gas Treatment	Oxy-combustor, Air combustion, CO_2 processing
System Performance	Component Reliability, Capacity Factor, SOFC Degradation

IGFC System Design Choices: Gasifier



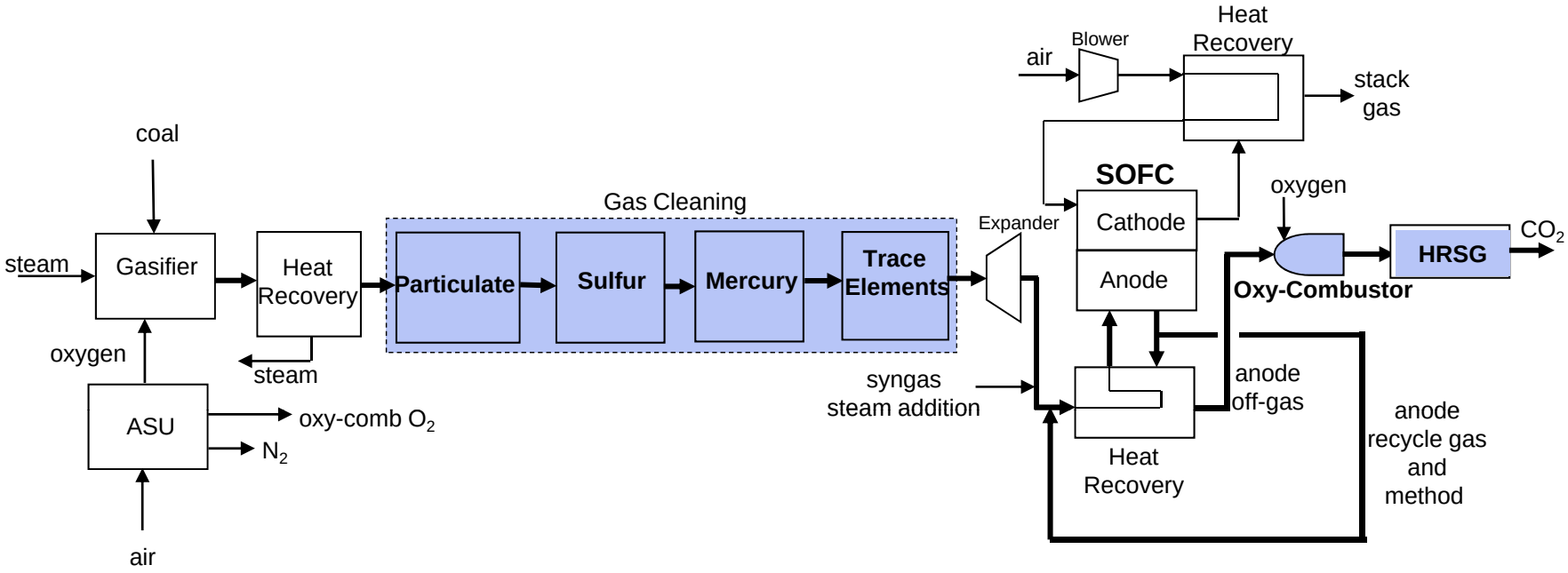
Gasifier Design

- Conventional (entrained flow)
  - ✓ low methane
  - ✓ nominal methane (e.g. 5%)
- Catalytic
  - ✓ oxygen-steam
  - ✓ steam with processed gas recycle
  - ✓ staged concepts

Gasifier Operation / Performance

- Operating T/P
- Carbon loss
- Gasifier steam (saturated, superheated)

IGFC System Design Choices: Gas Cleaning / Carbon Capture

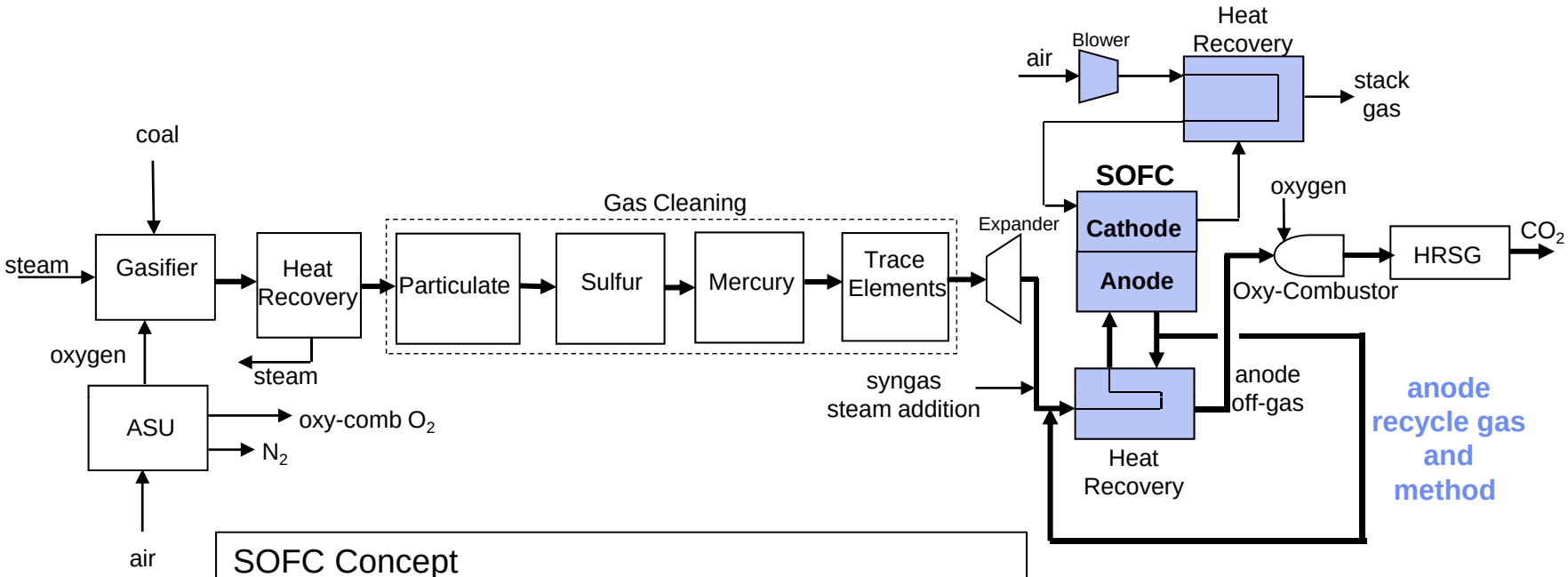


Gas Cleaning
- Dry Gas Cleaning
- Humid Gas Cleaning (maintain syngas above dew point)

Anode Off-Gas Treatment
- Oxy-combustion (CO_2 purification)
- Air burner / CO_2 absorption

Heat Recovery
- Steam Bottoming Cycle (steam conditions)
- Process Steam Requirements w/o steam cycle

IGFC System Design Choices: SOFC Power Block



SOFC Concept
- Separated Anode/Cathode off-gas

SOFC Operating Pressure
- Atmospheric
- Pressurized

SOFC System Design
- Anode off-gas - with or w/o recycle
- Cathode gas - with or w/o recycle
- Method of recycle (e.g. blower, eductor)

SOFC Operating Conditions
- Voltage
- Fuel Utilization
- Cell Temperature, Temperature Gradient

Illustrated IGFC Development Path – Conventional Gasifier

Case Parameter	Gasifier	SOFC Pressure / Overpotential	Capacity Factor	Degradation (%/1000 hr)	SOFC Cost ($/kW SOFC power)
Base Case	'CoP'	Atm / 120 mV	80	1.5	296
Reduced Degradation	'CoP'	Atm / 120 mV	80	0.2	296
Cell Performance	'CoP'	Atm / 90 mV	80	0.2	296
Cell Performance	'CoP'	Atm / 50 mV	80	0.2	296
CF (%)	'CoP'	Atm / 50 mV	85	0.2	296
SOFC Pressure	'CoP'	290 psia / 50 mV	85	0.2	442
CF (%)	'CoP'	290 psia / 50 mV	90	0.2	442
SOFC cost	'CoP'	290 psia / 50 mV	90	0.2	80% stack cost
Base Case with NG injection	'CoP'	Atm / 90 mV	80	1.5	296

Illustrated IGFC Development Path: Catalytic Gasifier

Case Parameter	Gasifier	SOFC Pressure / Overpotential	Capacity Factor	Degradation (%/1000 hr)	SOFC Cost ($/kW SOFC power)
Base Case	Catalytic	Atm / 120 mV	80	1.5	296
Reduced Degradation	Catalytic	Atm / 120 mv	80	0.2	296
Cell Performance	Catalytic	Atm / 90 mV	80	0.2	296
Cell Performance	Catalytic	Atm / 50 mv	80	0.2	296
CF (%)	Catalytic	Atm / 50 mv	85	0.2	296
SOFC Pressure	Catalytic	290 psia / 50 mv	85	0.2	442
CF (%)	Catalytic	290 psia / 50 mV	90	0.2	442
SOFC cost	Catalytic	290 psia / 50 mV	90	0.2	80% stack cost

Gasifier Design / Performance

- Conventional Gasifier – Analogous to CoP Concept
  - Temperature (°F): 1830
  - Pressure (psia): 450
  - Oxygen/coal mass ratio: 0.68
  - Steam/coal mass ratio: 0.33
  - Syngas methane content (dry mole%): 5.9
  - Carbon loss (wt% coal carbon): 0.8
  - Cold gas efficiency (%, HHV): 81
- Catalytic Gasifier – Single Stage Oxygen/Steam
  - Temperature (°F): 1300
  - Pressure (psia): 975
  - Oxygen/coal mass ratio: 0.19
  - Steam/coal mass ratio: 1.44
  - Syngas methane content (mole%): 31
  - Carbon loss (wt% coal carbon): 5
  - Cold gas efficiency (%, HHV): 95

SOFC Design Basis

Fuel Cell System	
cell stack inlet temperature, ºC (ºF)	650 (1202)
cell stack outlet temperature, ºC (ºF)	750 (1382)
cell stack outlet pressure, MPa (psia)	0.12 (15.6)
fuel single-step utilization, %	75
fuel overall utilization, %	90
stack anode-side pressure drop, MPa (psi)	0.0014 (0.2)
stack cathode-side pressure drop, MPa (psi)	0.0014 (0.2)
power density, mW/cm^2	400
stack over-potential, mV	120, 90, 50
operating voltage estimation method	Ave. Nernst – overpotential
cell degradation rate (% per 1000 hours)	1.5 and 0.2
cell replacement period (% degraded)	20

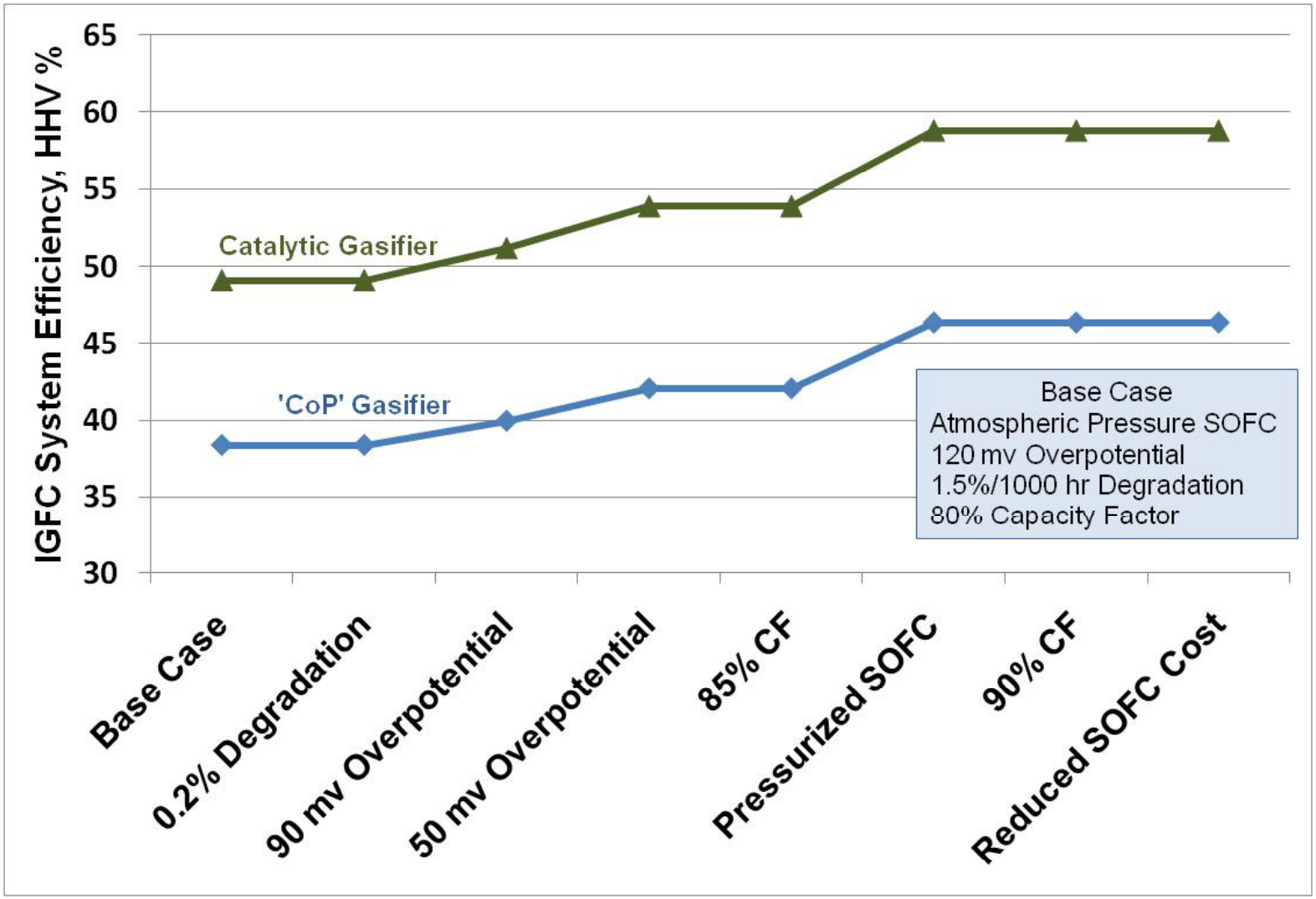
Atmospheric Pressure SOFC System Cost

Atm-pressure SOFC System Component (400 mW DC/cm^2)	Cost (2007$)
DOE Goal: SOFC Stacks + Enclosures ($/kW net plant)	175
SOFC Stacks + Enclosures ($/kW SOFC)	165
Inverters ($/kW SOFC) (NIST SiC technology)	82
Total SOFC “Unit” Factory Cost using NIST Inverters ($/kW SOFC)	247
Module Transportation cost ($/kW SOFC)	12
Power Island Foundation cost ($/kW SOFC)	37
Total installed SOFC “Unit” ($/kW SOFC) w SiC technology	296

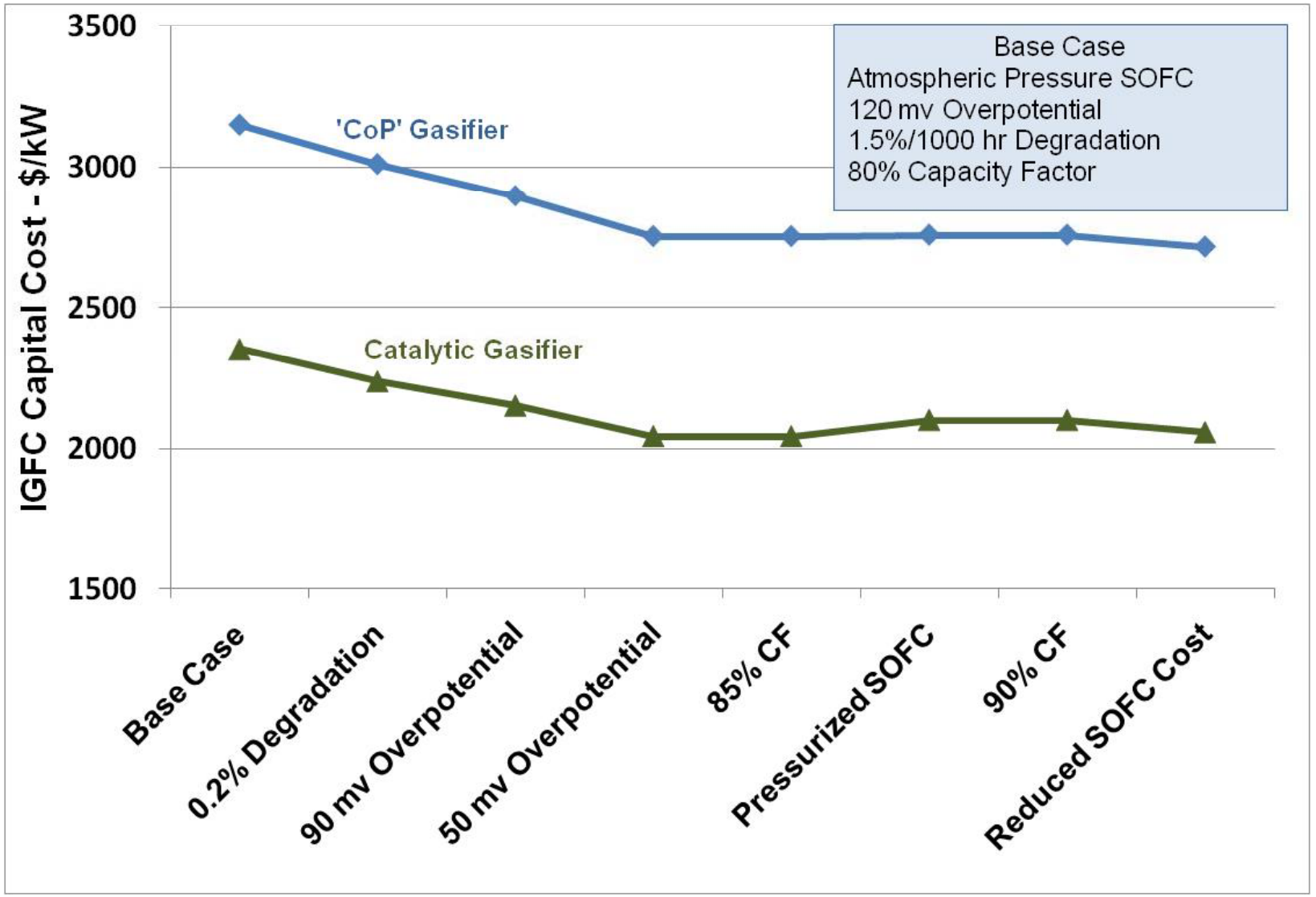
Pressurized SOFC System Cost

Pressurized SOFC System Component (500 mW DC/cm^2)	Cost (2007$)
SOFC Stacks ($/kW SOFC)	111
Pressure Enclosure cost ($/kW SOFC)	200
Inverters ($/kW SOFC) based on SiC technology	82
Module Transportation cost ($/kW SOFC)	12
Power Island Foundation cost ($/kW SOFC)	37
Total Installed Pressurized-SOFC “Unit” ($/kW SOFC) w SiC technology	442

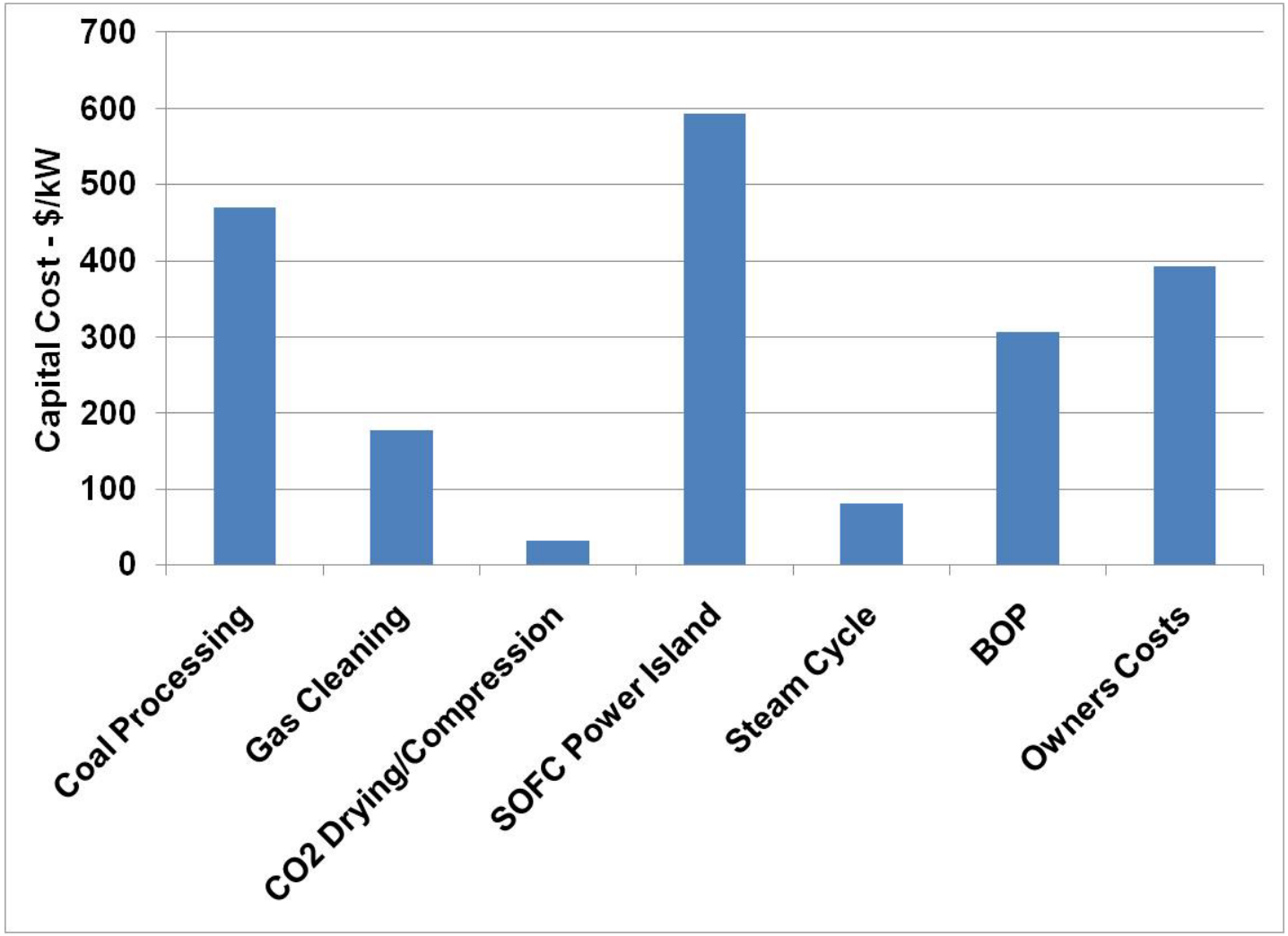
IGFC System Efficiency



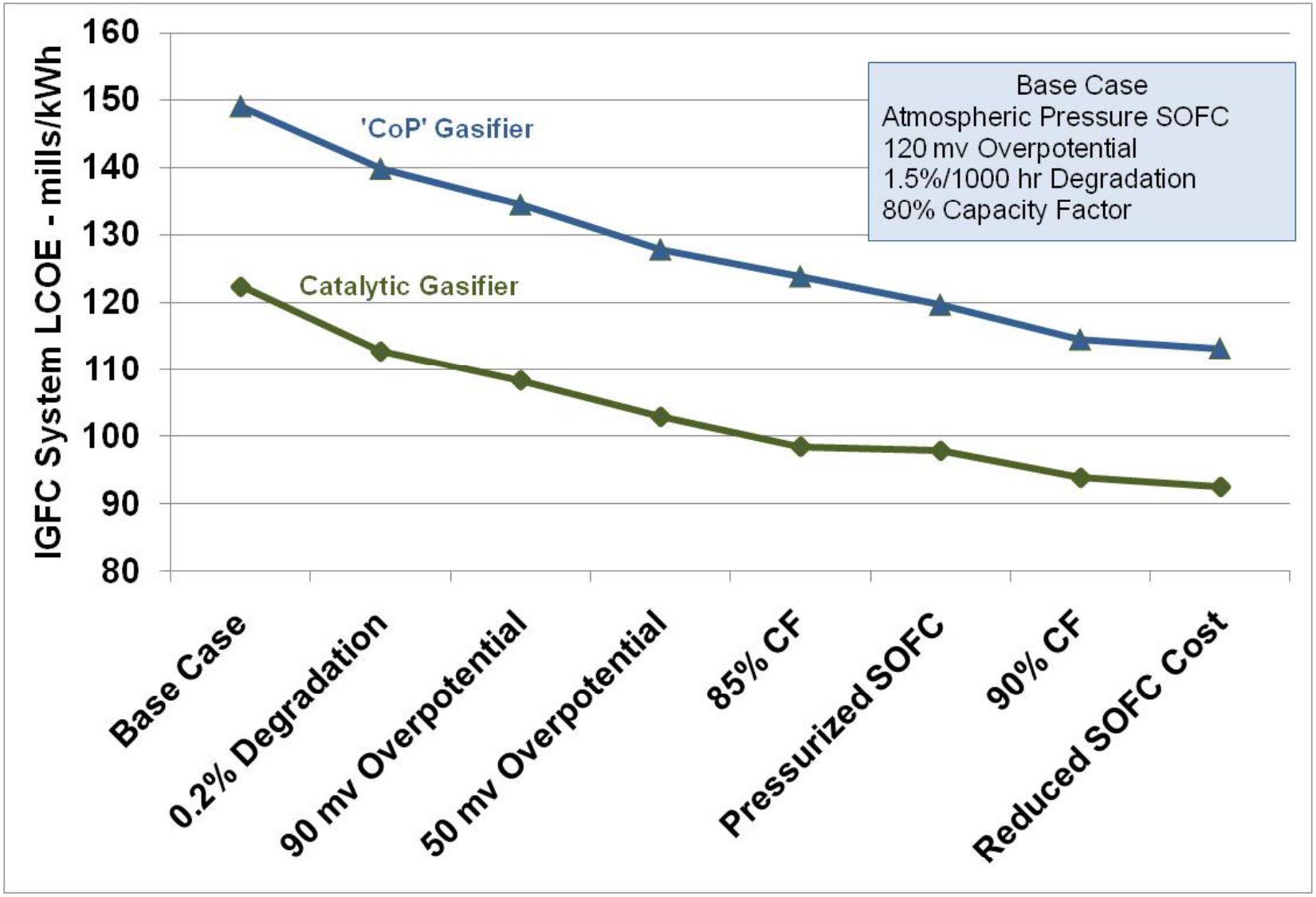
IGFC System Capital Cost



Capital Cost Distribution: Catalytic Gasifier Advanced Case

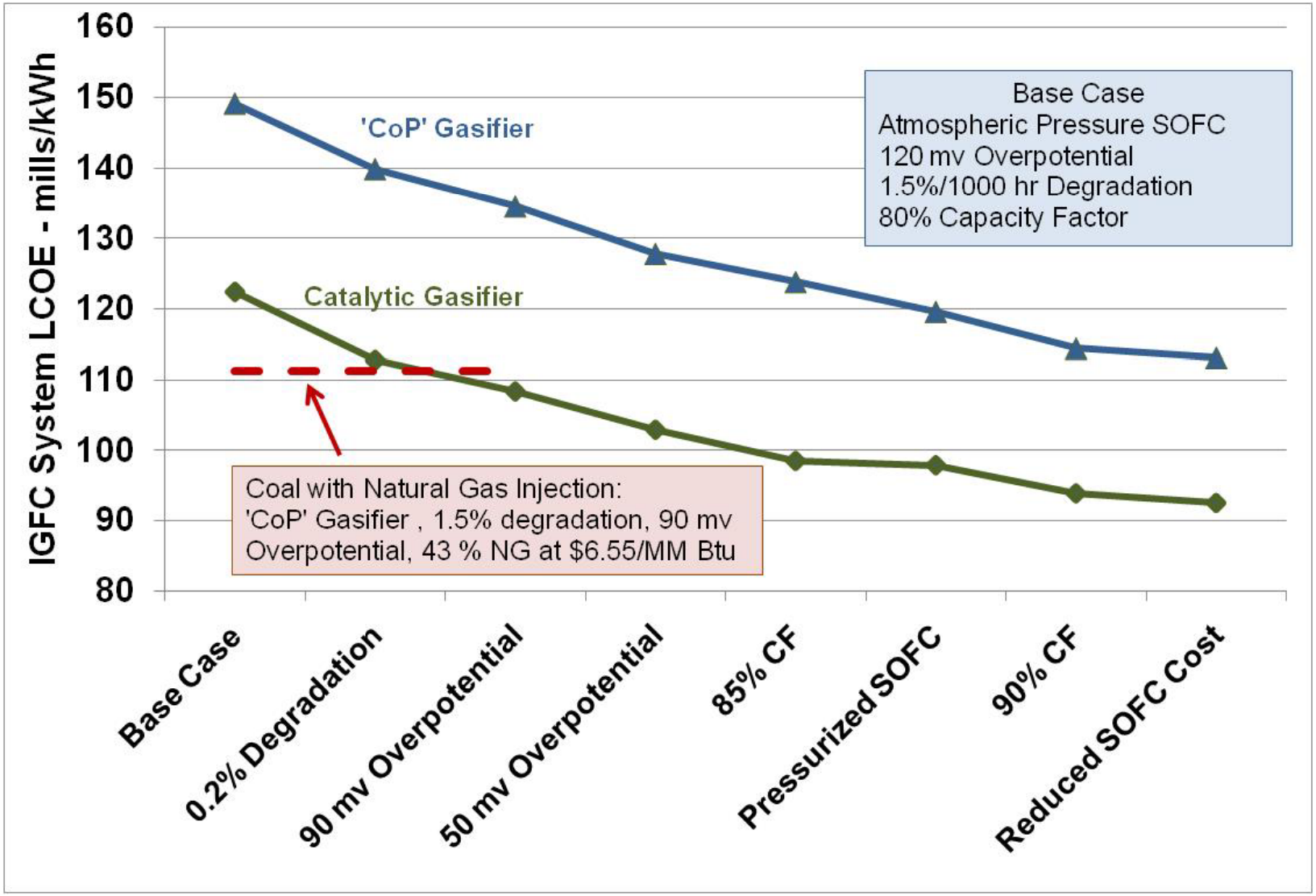


IGFC System Levelized Cost of Electricity



Cost Basis consistent with NETL Baseline Study; June 2007 $; IL #6 coal at $1.64/MMBtu, includes allocation for CO_2 transport , storage and monitoring

IGFC System Levelized Cost of Electricity



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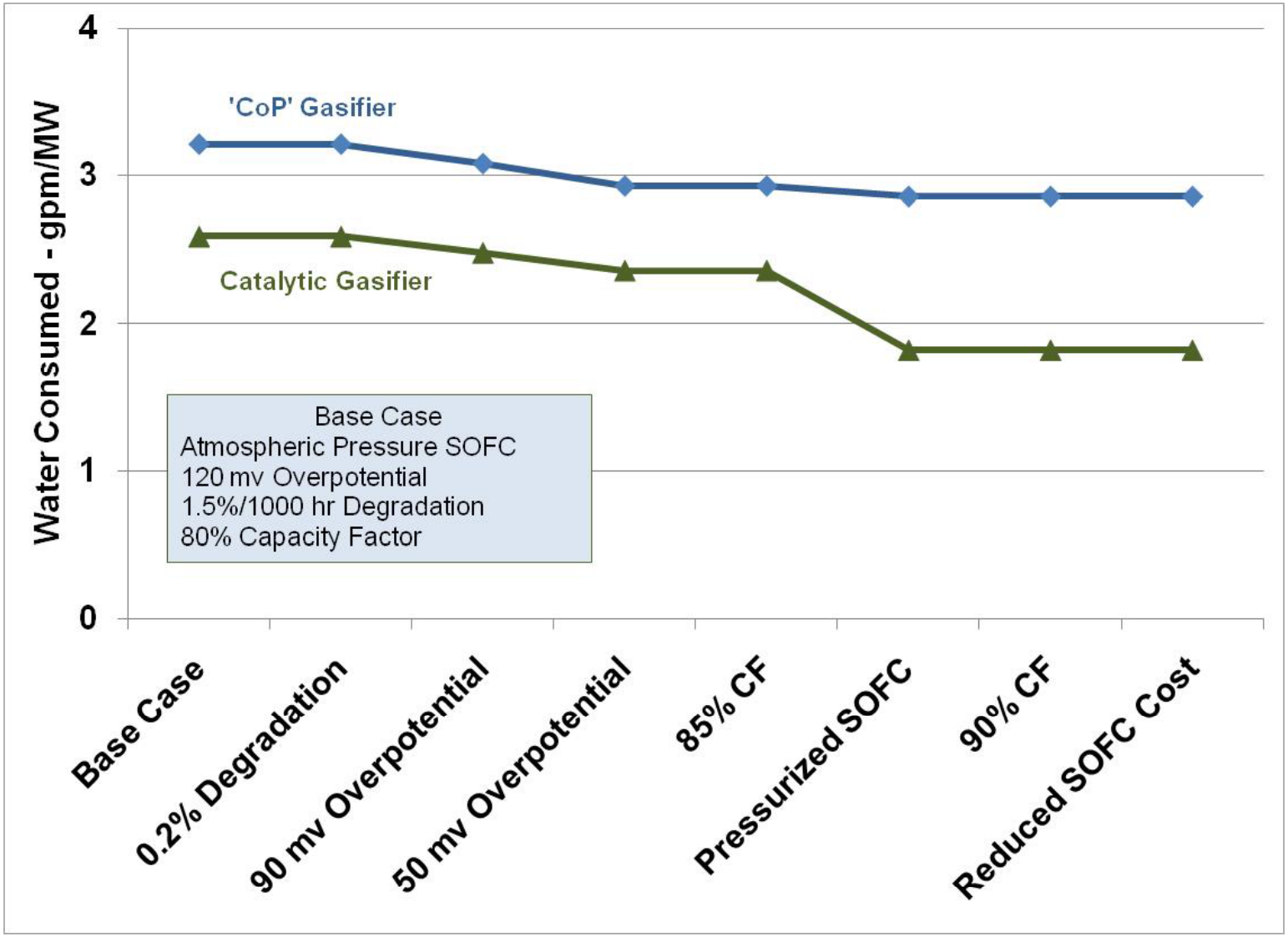
IGFC System Performance: Catalytic Gasifier Advanced Case

- Power Generation (488 MW)
  - SOFC Power (499 MW)
  - Syngas Expander (8 MW)
  - Steam Cycle (52 MW)
  - Auxiliaries (70 MW)
- Water Consumed
  - 1.8 gpm/MW (IGCC w CCS 9.0; PC w CCS 14.1)

IGFC System Water Use



Assessment

- Commercial IGFC system based on current SOFC test data shows LCOE comparable to NETL Baseline Study IGCC and PC
- Significant benefit in terms of efficiency, capital cost and LCOE result from
  - Increased methane in the anode feed (options include gasifier design, syngas methanation, natural gas injection)
  - SOFC performance (reduced overpotential, reduced degradation)
  - SOFC elevated pressure operation
- Water use is significantly lower than alternative fossil based systems

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