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Integrated Gasification Fuel Cell Performance and Cost Assessment

Presented by Phil DiPietro, Division Director

Situational Analysis and Benefits Division

Office of Systems Analyses and Planning, NETL

- **Co-analysts**
  - Kristin Gerdes
  - Dale Keairns
  - Dick Newby
  - And help and advice from Eric Grol and Jan Thijssen

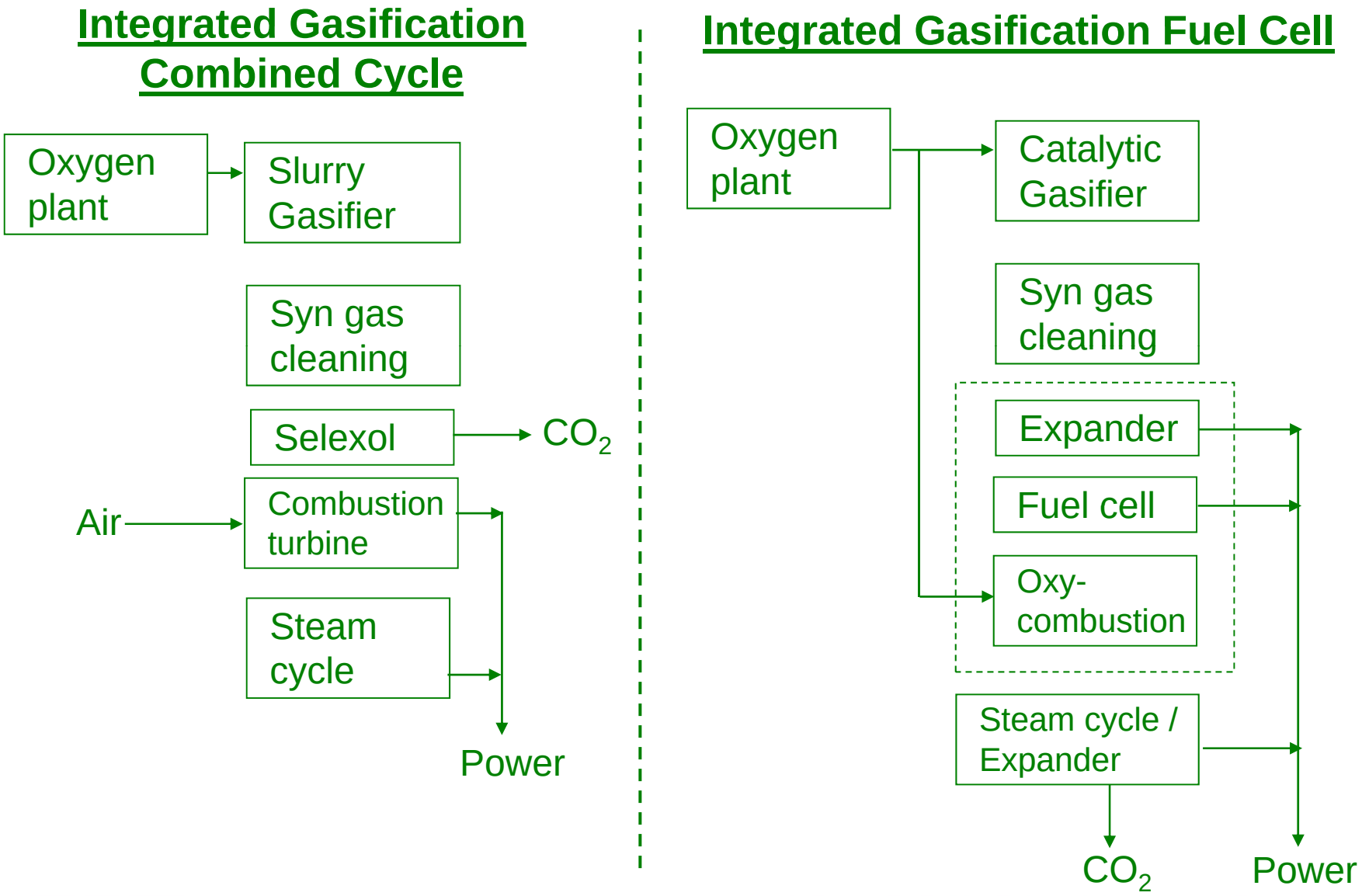
Summary Points

- **Paradigm change: Fuel cells offer higher efficiency and lower capital**
- **Percent CO_2 capture matters: At \$50/mtCO_2, 100% CO_2 capture saves 0.5 cents/kWh compared to 90%**

Objective: evaluate a power plant based on fuel cell conversion of syngas as an investment option

- Scope: central station, baseload duty cycle
- Assess atmospheric and pressurized fuel cell stacks
- Assume DOE goals for cost and performance of the fuel cell block
- Use unit operation cost data from IGCC studies
- Include cost of CO_2 storage, emissions
- Quantify water use/consumption

Configurations of Advanced Coal-Based Power Plants



Sub-system Technology

Sub-system	IGCC	IGFC (atm)	IGFC (press)
Gasifier	Slurry Fed	Catalytic	
Gas Cleaning	Dry	Dry	Humid
Syngas Conversion	Advanced “F” Turbine	Fuel cell, 20 psia	Fuel cell, 270 psia
Steam Cycle	Subcritical	Subcritical	None
Carbon Capture	Selexol (90%)	Oxy-combustion of anode off-gas (~99%)	

Performance and Cost Summary

	Conventional IGCC	IGFC (Atm SOFC)	IGFC (Press SOFC)
Efficiency (%, HHV)	**32.5**	**49.4***	**56.2****
CO_2 Emissions (kg CO_2/MWh net)	90	6	6
Water Usage (gal/MWh net)	570	240	170
Capital Cost (2007$/kW)	**2,400**	**2,000**	**1,800**
LCOE (cents/kWh)	10.2	8.8	7.9

** The efficiency without CO_2 compression is 52.6%*
*** The efficiency without CO_2 compression is 60.1%*

Fuel Cell Performance Assumptions

SOFC Parameter	SOFC (atm)	SOFC (press)
Inlet/Outlet Temperature	650 / 800 C	
Fuel Single Pass Utilization	70%	
Current Density	500 mA/cm^2	
Outlet Pressure	20 psia	270 psia
Nernst Potential*	0.84	0.92
Stack Overpotential	40 mV	50 mV
Degradation Rate	0.1% / 1,000 hrs	0.1% / 1,000 hrs

** Nernst calculated based on SOFC exit conditions that includes operating pressure and gas composition*

Fuel Cell Cost Assumptions

- **700 $/kW AC output from the stack ($2007)**
  - Installed cost
  - Consistent with DOE cost target
  - Includes associated heat exchangers, blowers, controls and DC-to-AC rectifier

- **Replacement cost assumed to be $100/kW AC output from the stack ($2007)**

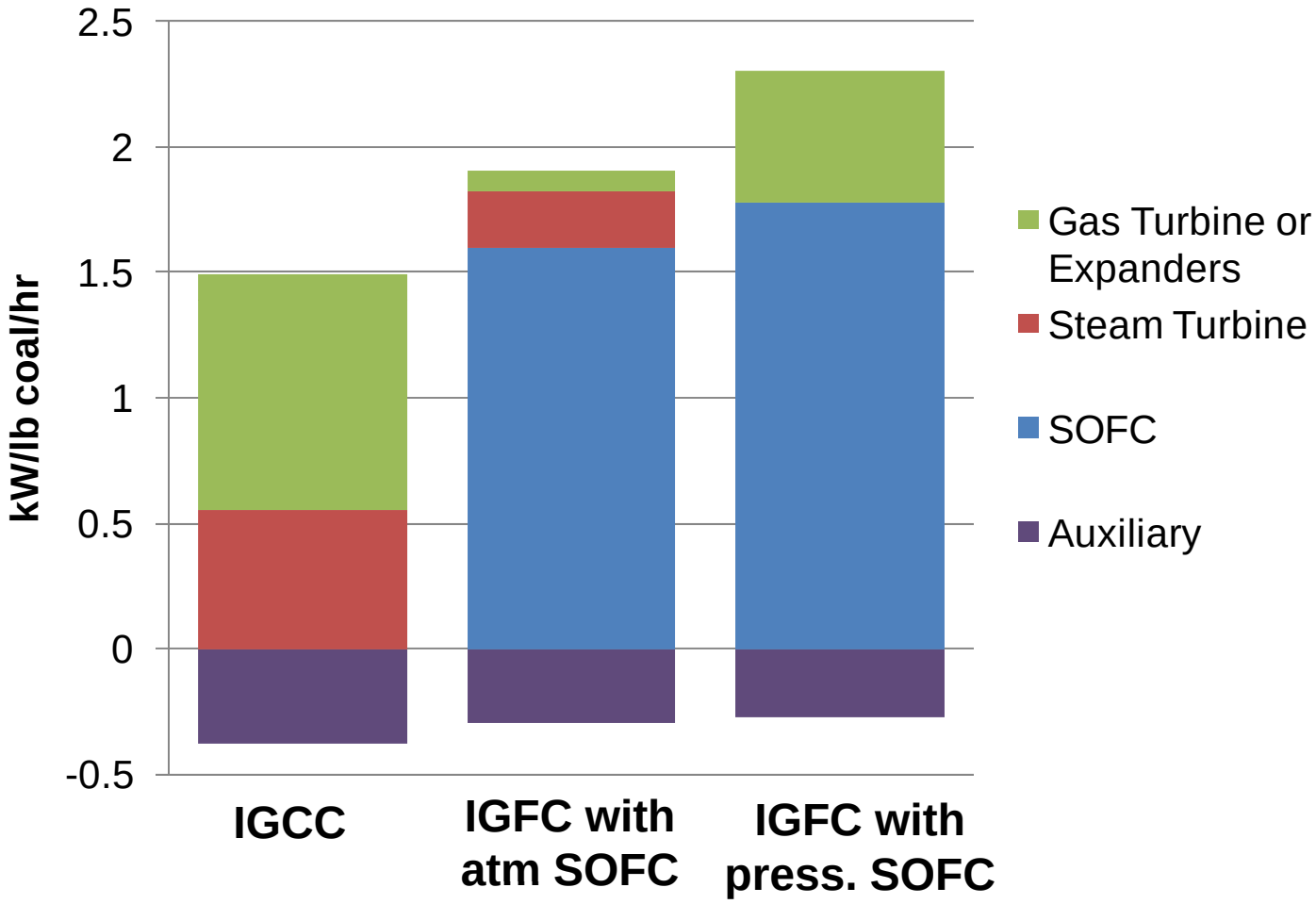
Catalytic Gasifier

- **Good match with the fuel cell**
  - Consumes less O_2
    - ~ 0.25 kg O_2 per kg coal versus ~ 0.7 for slurry fed
  - Makes methane
    - 17 vol% in syngas versus ~ 0 vol% for slurry
  - Uses steam
- **Large area of technology risk is in catalyst recovery/regeneration**
  - We use Exxon assumption of 2/3 recovery
  - Adds estimated 0.20 cents/kWh O&M cost

Oxy-combustion of Anode Off-gas

- **Utilizes remaining fuel value and raises steam quality**
- **Eliminates water gas shift**
- **Avoids “touching” CO2, enables near 100% capture**
- **Un-reacted oxygen in effluent is an area for future study**

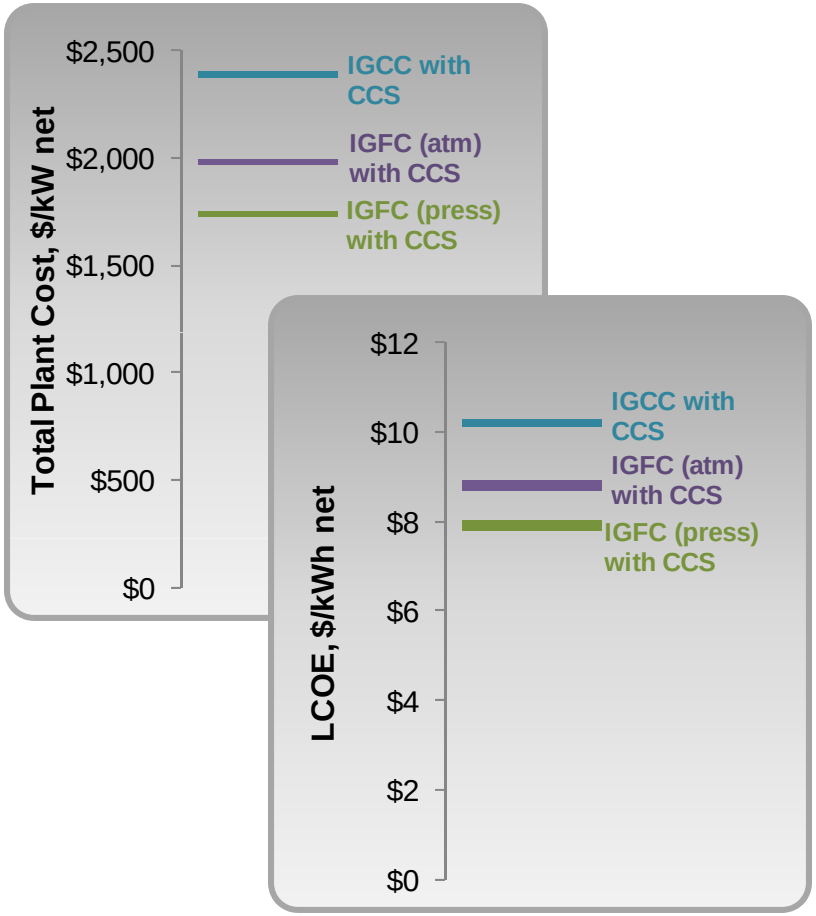
Design for High SOFC Capacity Drives System Efficiency



Cost Assessment of IGFC

- **Cost Approach**
  - Fuel cell system installed cost of $700/kW AC output from stack (2007 dollars)
  - Other major unit costs scaled from range of studies
  - O&M costs and financial parameters consistent with NETL Bituminous Baseline Report (August 2007)

- **High efficiency of IGFC and ease of CO_2 capture drives down capital costs and LCOE relative to today's IGCC technology**

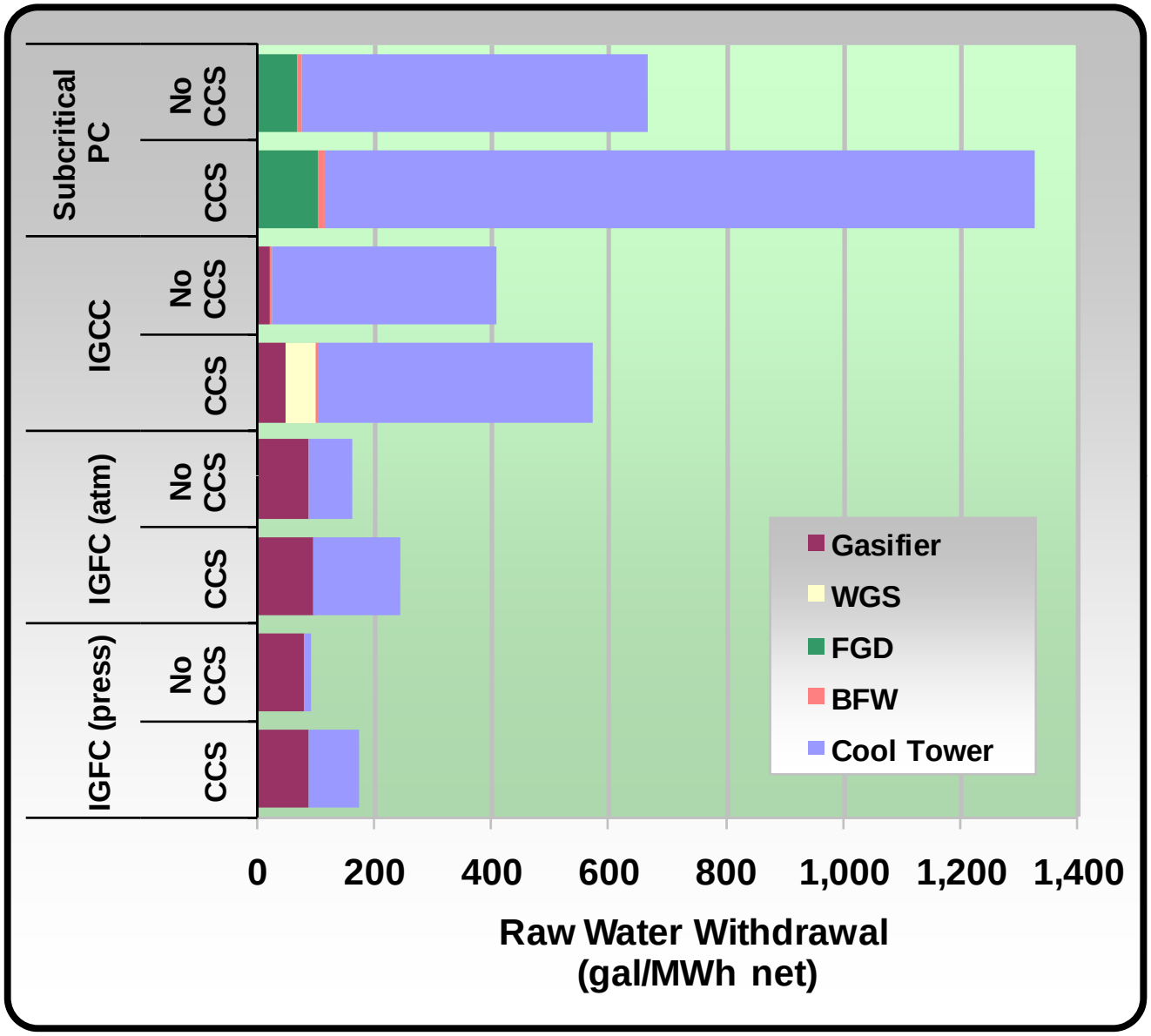


IGCC and IGFC Capital Costs, $/kW

	IGCC	IGFC	Adv IGFC	Drivers of Cost Differences *Relative to IGCC*
Gasification, ASU	1,085	620	550	• Catalytic Gasification (Low Temp, Oxygen) (-) • Catalyst/Ash Handling and Coal Prep (+) • System Efficiency (-)
Gas Cleaning	235	175	220	• Sulfur Polishing (+) • Humid Gas Cleaning (Adv IGFC only) (+) • System Efficiency (-)
Power Island	455	770	610	• Fuel Cell System (+) • Parasitic Load (-)
CO_2 Capture	245	135	125	• Oxycombustion v Selexol (-) • System Efficiency (-)
Balance of Plant	370	285	235	• System Efficiency (-)
Total	**2,390**	**1,985**	**1,740**	

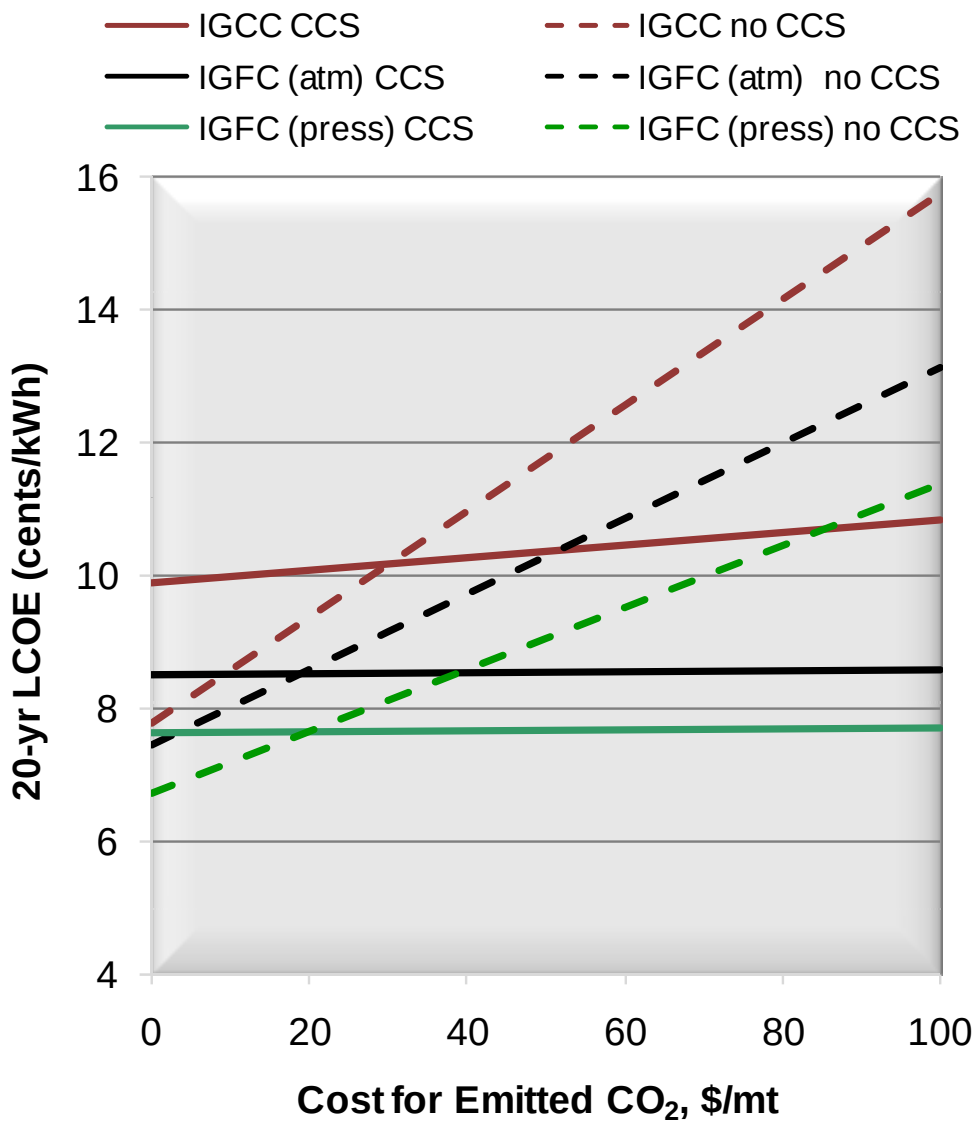
IGCC and IGFC with CCS LCOE

	IGCC	IGFC (atm)	Adv IGFC	Drivers of Cost Differences *Relative to IGCC*
Total Plant Costs ($/kW)	2,390	1,985	1,740	
Variable O&M (cents/kWh)	0.8	1.1	1.1	• Stack Replacement (+) • Gasifier Catalyst, Sorbents (+) • System Efficiency (-)
Fixed O&M, $/kW/yr	44	47	45	• Plant Size (+) • System Efficiency (-)
Fuel Cost, cents/kWh	1.9	1.2	1.1	• System Efficiency (-)
CO2 Transport and Storage Cost, cents/kWh	0.35	0.25	0.20	• System Efficiency (-) • Percent CO_2 captured (+)
LCOE (20-yr), cents/kWh	**10.2**	**8.8**	**7.9**	


Subcritical PC
IGCC
IGFC (atm)
IGFC (press)
No CCS
CCS
Gasifier
WGS
FGD
BFW
Cool Tower
0
200
400
600
800
1,000
1,200
1,400
Raw Water Withdrawal (gal/MWh net)

Effect of net CO_2 emissions on LCOE

Platform	Coal Use, Btu/kWh	Net CO_2 Emissions, $kgCO_2/MWh$	Variable Cost for Fuel, cents/kWh	Variable Cost of CO_2 Emissions @ $50/$mtCO_2$, cents/kWh
IGCC	10,500	90	1.9	0.5
IGFC (Atm)	6,910	6	1.2	0.03
IGFC (Press)	6,070	6	1.1	0.03
PC (no capture)	9,280	860	1.6	4.3
PC (90% capture)	13,720	130	2.3	0.7



LCOE in a Carbon Constrained Scenario

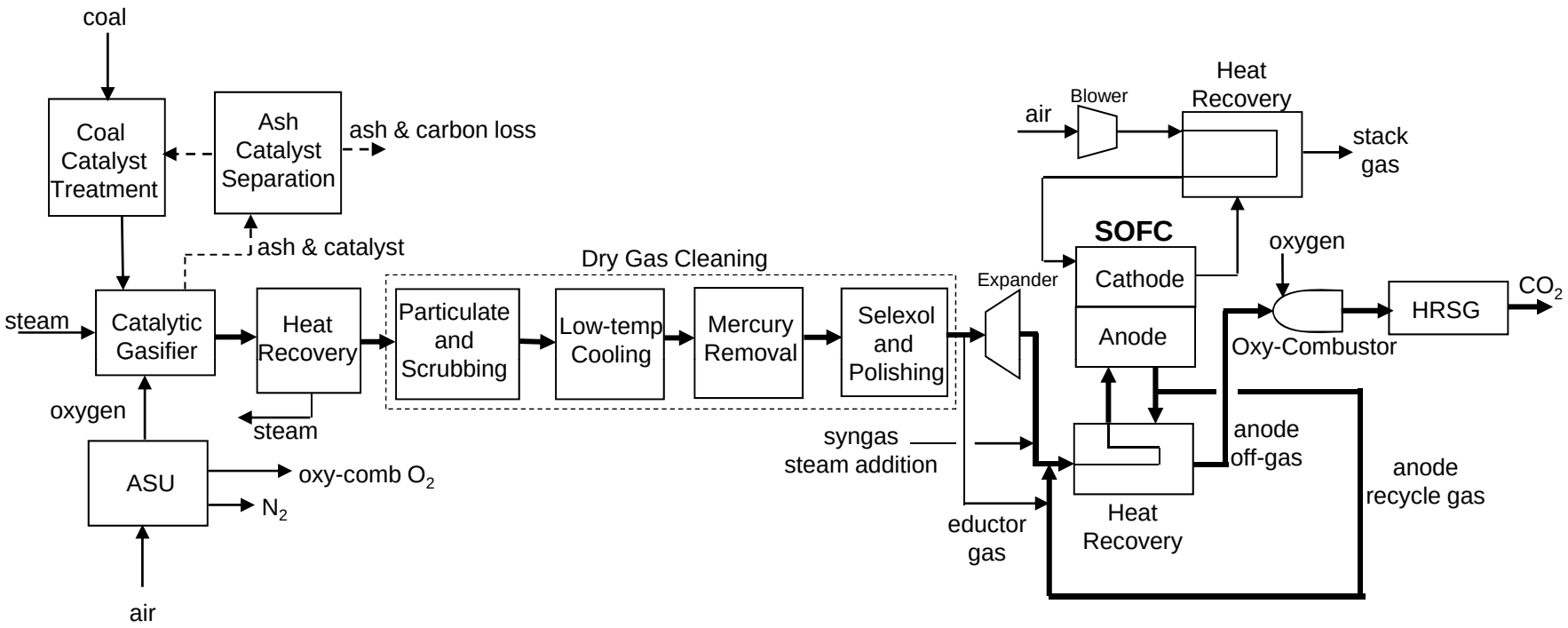
IGCC, CO_2 capture becomes economically preferable to no capture at $30/mt CO_2

Fuel cells reduce the cross over to $20/mt CO_2

Conclusions

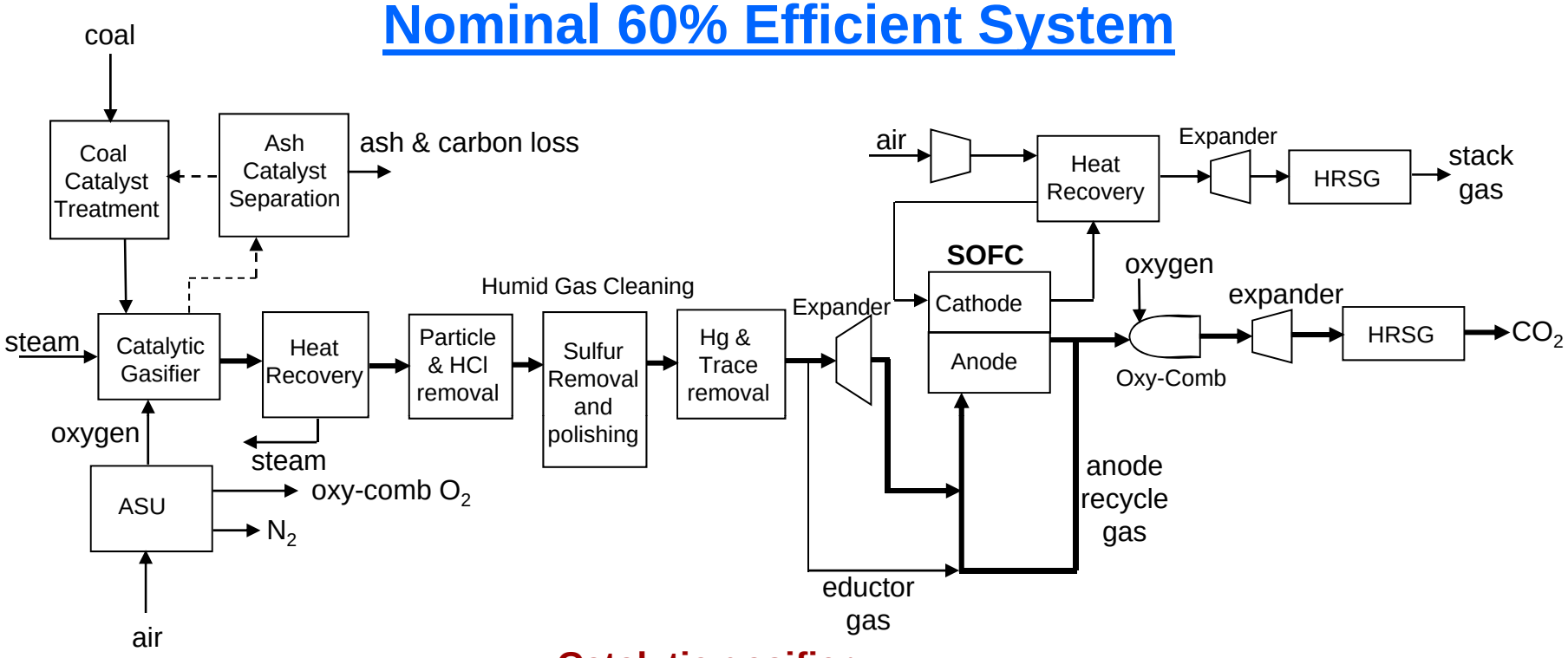
- **IGFC platforms, based on a fuel stack that meets the program goals, offers both a step change in efficiency and reduced capital cost per kW and higher percent CO_2 capture and reduced water use**

Advanced IGFC with Atmospheric SOFC and DGC Nominal 50% Efficient System

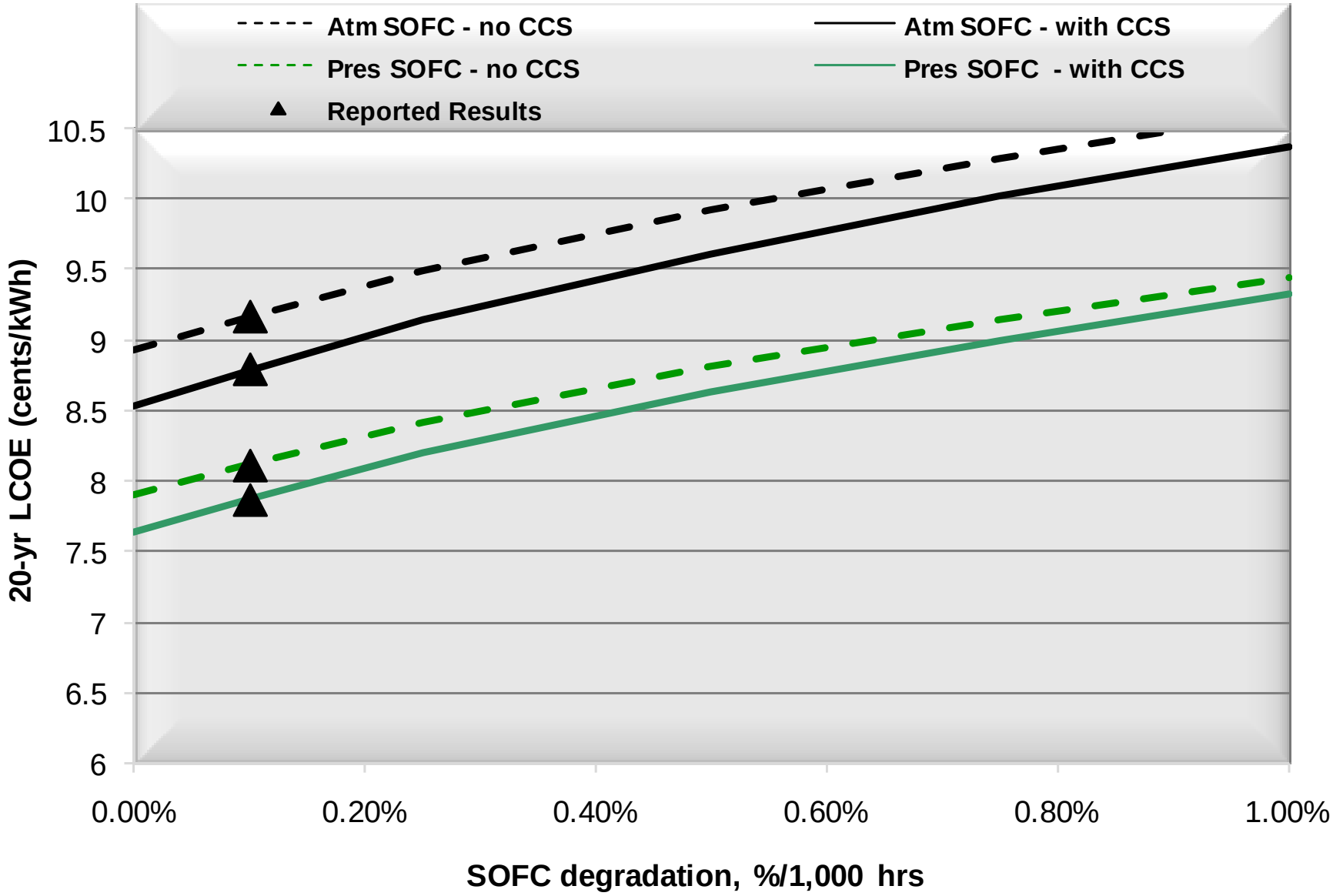


- **Catalytic gasifier**
- **Oxy-combustor**
- **Recycle gas eductor**

High Performance IGFC System
Nominal 60% Efficient System



- **Catalytic gasifier**
- **Humid gas cleaning**
- **Pressurized SOFC**
- **Oxy-combustor**
- **Recycle gas eductor**


Atm SOFC - no CCS
Atm SOFC - with CCS
Pres SOFC - no CCS
Pres SOFC - with CCS
Reported Results
20-yr LCOE (cents/kWh)
10.5
10
9.5
9
8.5
8
7.5
7
6.5
6
0.00%
0.20%
0.40%
0.60%
0.80%
1.00%
SOFC degradation, %/1,000 hrs