NATIONAL ENERGY TECHNOLOGY LABORATORY

Analysis of Solid Oxide Fuel Cell Plant Configurations with CCS

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    - Travis Shultz
    - William Summers
    - Kristin Gerdes
    - Walter Shelton

Objectives

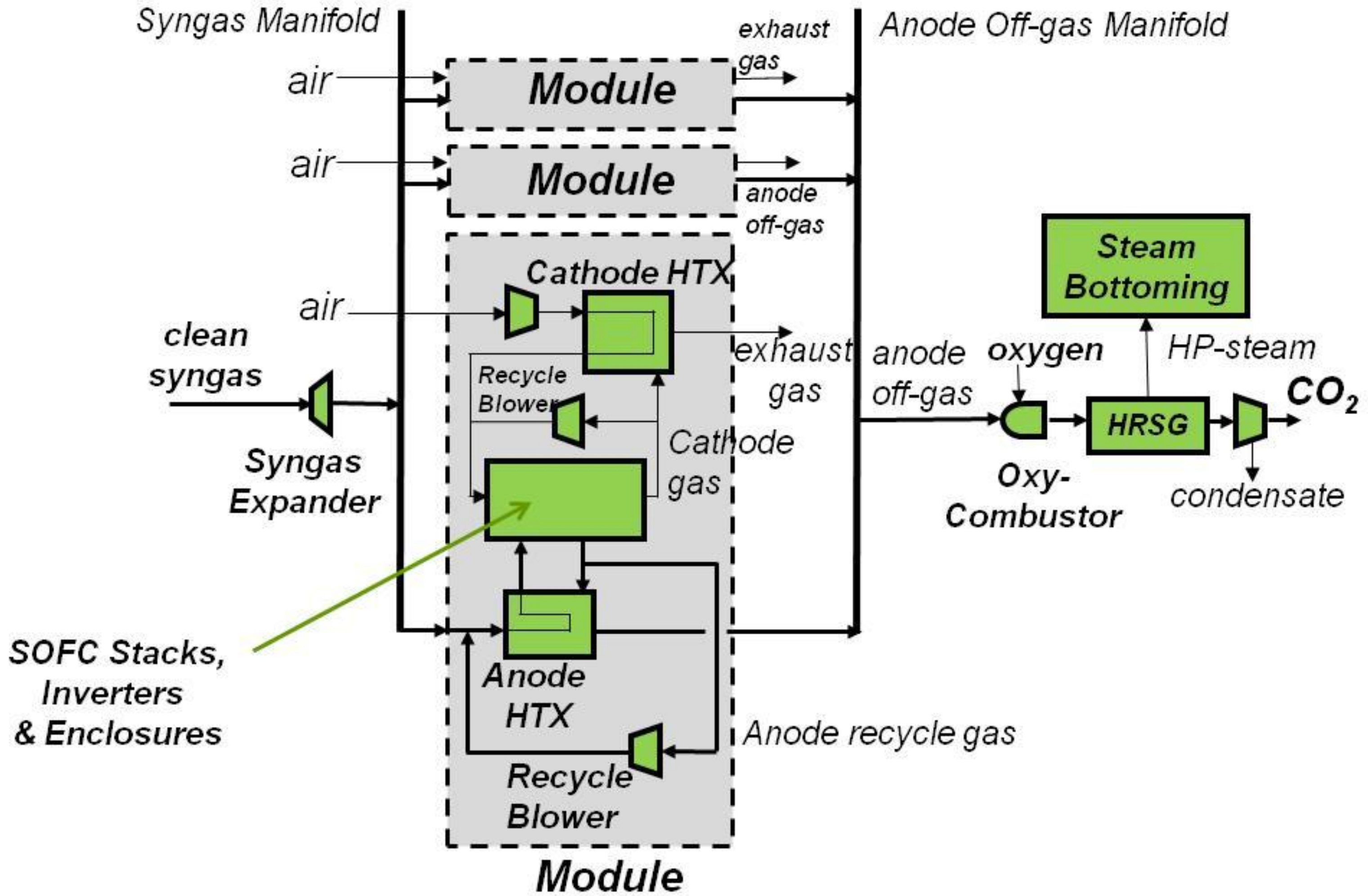
- Develop technology pathways that project plant performance and cost of electricity for Integrated Gasification Fuel Cell (IGFC) and Natural Gas Fuel Cell (NGFC) Plant Configurations with carbon capture and storage (CCS)
- Select pathways that
  - ✓ Focus on SOFC power block technology advances and
  - ✓ Alternate pathway to include gasifier advances for high methane syngas for IGFC systems
- Utilize site, fuel and economic assumptions consistent with the NETL Bituminous Coal Baseline report
- Compare pathway results to ‘Today’s fossil plants’ with and w/o CCS
  - ✓ Supercritical PC
  - ✓ IGCC
  - ✓ NGCC

Design Basis Common to All Cases

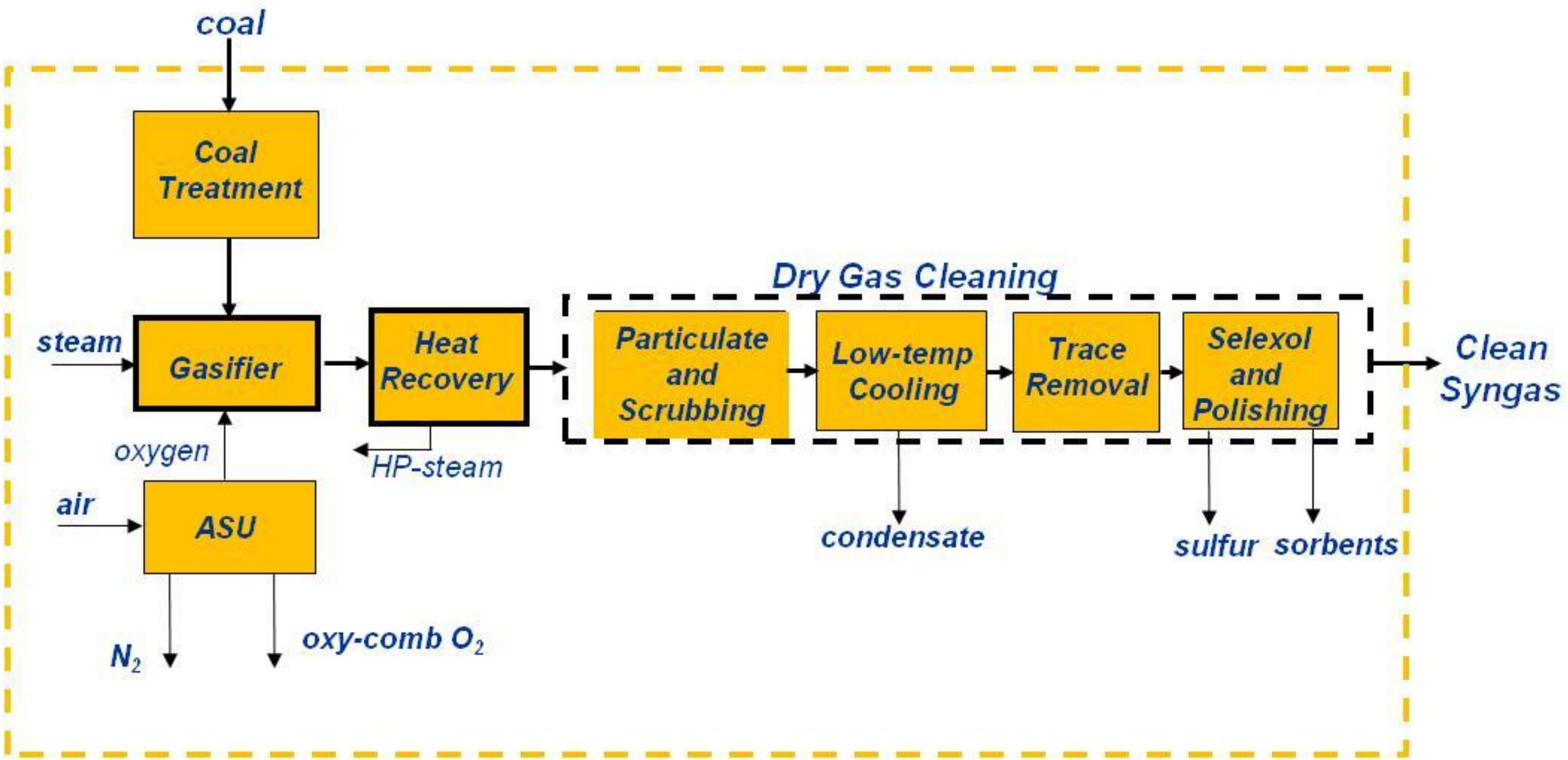
- **Consistent with NETL Bituminous Coal Baseline Report**
- **Site: mid-western U.S.; ISO conditions**
- **Plant Boundary: total plant facility**
  - COE includes transport, storage and monitoring of CO_2
- **Fuels: IL #6 Coal and Natural Gas**
- **Plant Capacity: 550 MWe with carbon capture & storage**
- **Conventional Cryogenic Air Separation**
- **Gas Cleaning for IGFC Plants: Dry Gas Cleaning**

Design Basis: SOFC Power Island

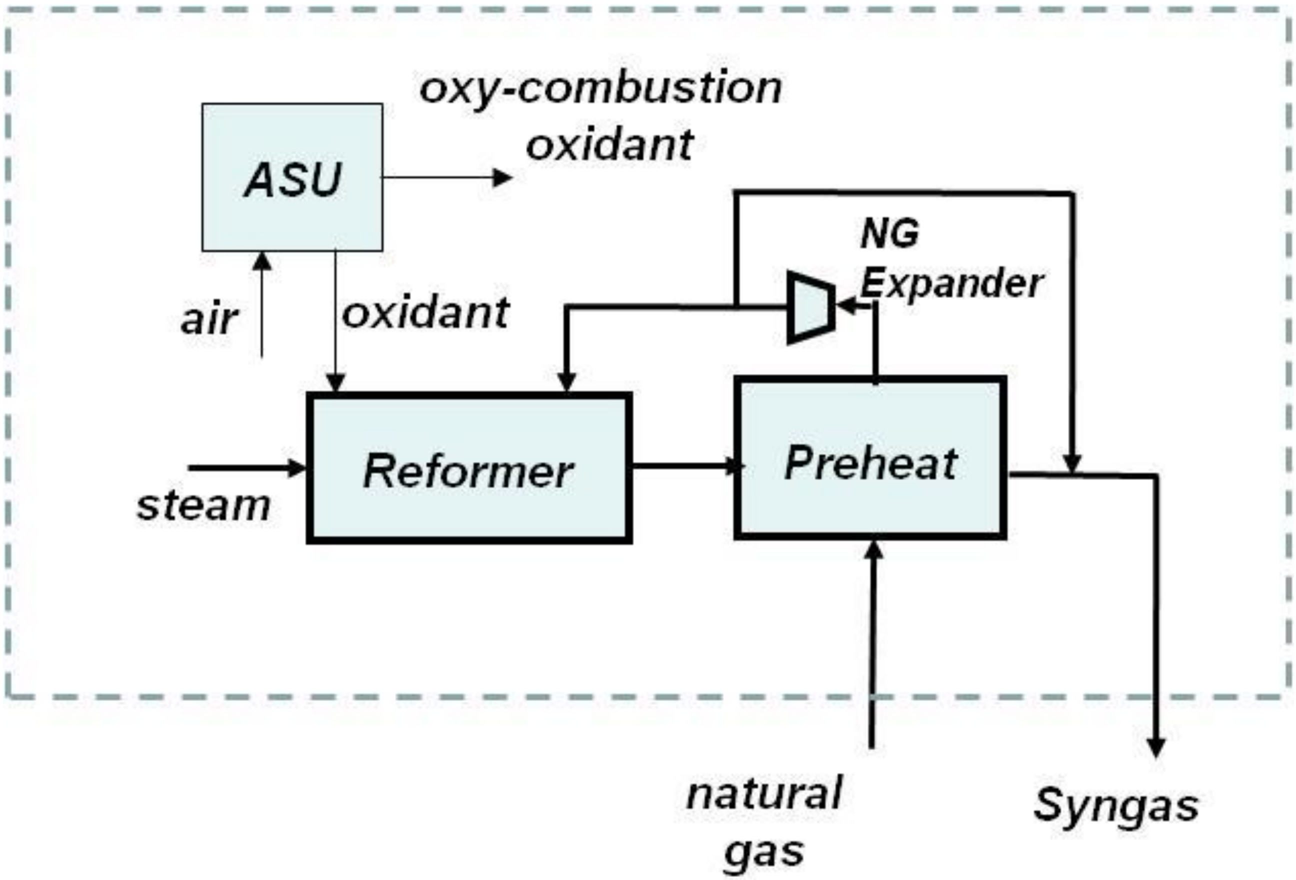
- *Planar SOFC technology*
- *Separate cathode and anode off-gas*
- *Cathode and anode gas recycle*



IGFC Gasification Process

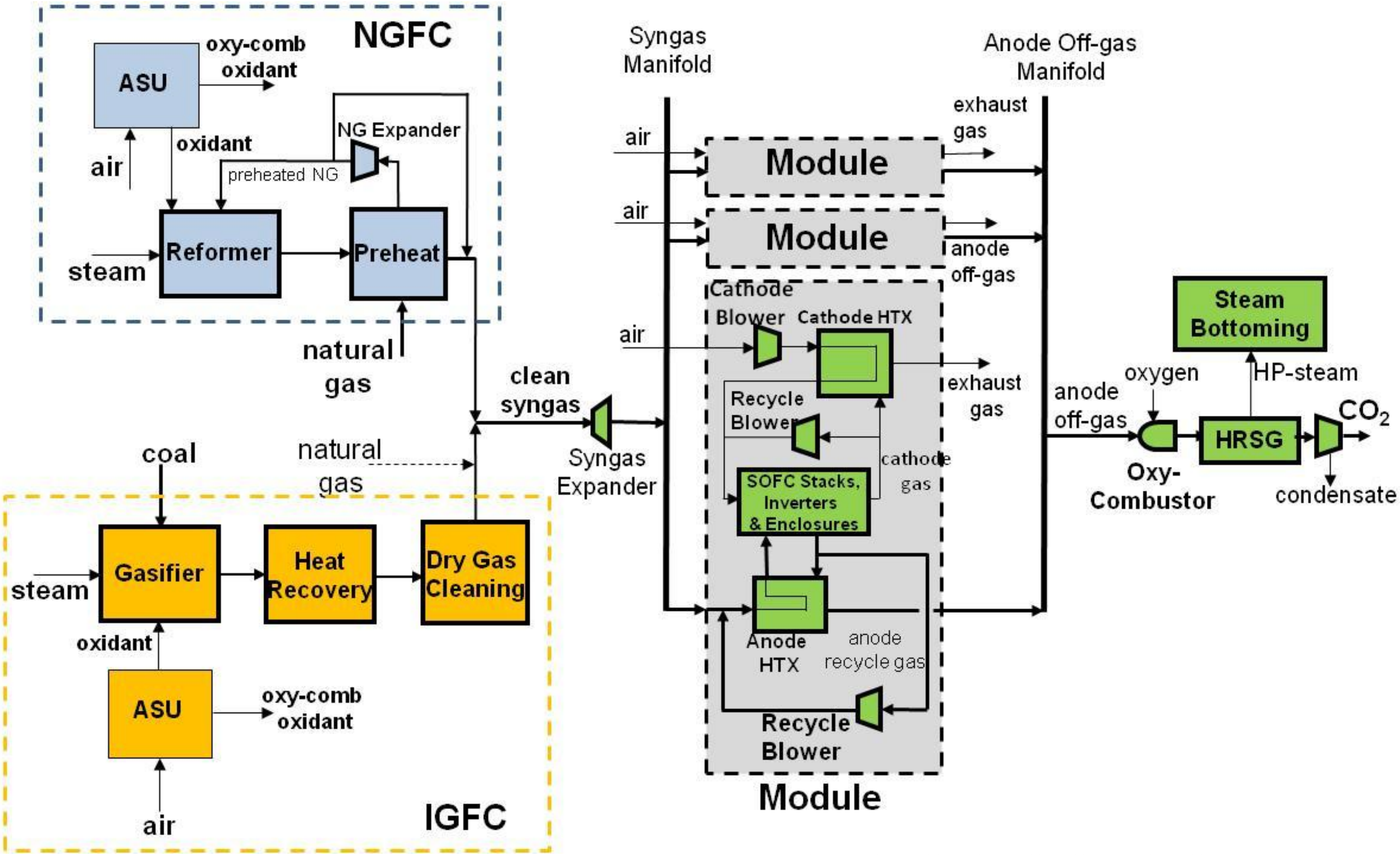


NGFC Natural Gas Supply



SOFC Plant Concepts

Pathways consider alternate fuel supply and SOFC operating pressure
(NGFC with external and internal reforming; IGFC with conventional and catalytic gasifiers)



Design Basis: SOFC

- **Carbon deposition control: (atomic O / atomic C) > 2.0**
- **Operating voltage = stack inlet Nernst potential – overpotential**
- **Baseline Conditions (consistent with current test data and cost)**
  - 140 mV overpotential
  - 1.5%/1000 hrs degradation
  - 5.9% gasifier methane content
  - 97% inverter efficiency
  - $296/kW Atm. Pressure SOFC stack unit installed cost
  - 80% plant capacity factor
- **Advancements**
  - 70 mV overpotential
  - 0.2%/1000 hrs degradation
  - 10.2% conventional gasifier methane content
  - 30% catalytic gasifier methane content
  - 98% inverter efficiency
  - $268/kW Atm. Pressure SOFC stack unit installed cost
  - 85% and 90% plant capacity factors
  - 285 psia pressurized SOFC
  - Internal catalytic SOFC reforming (applicable for NGFC plants)

Pathway Study Process Cases

- *Conventional Gasifier Pathway*
- *Catalytic Gasifier Pathway*
- *Natural Gas Pathway*

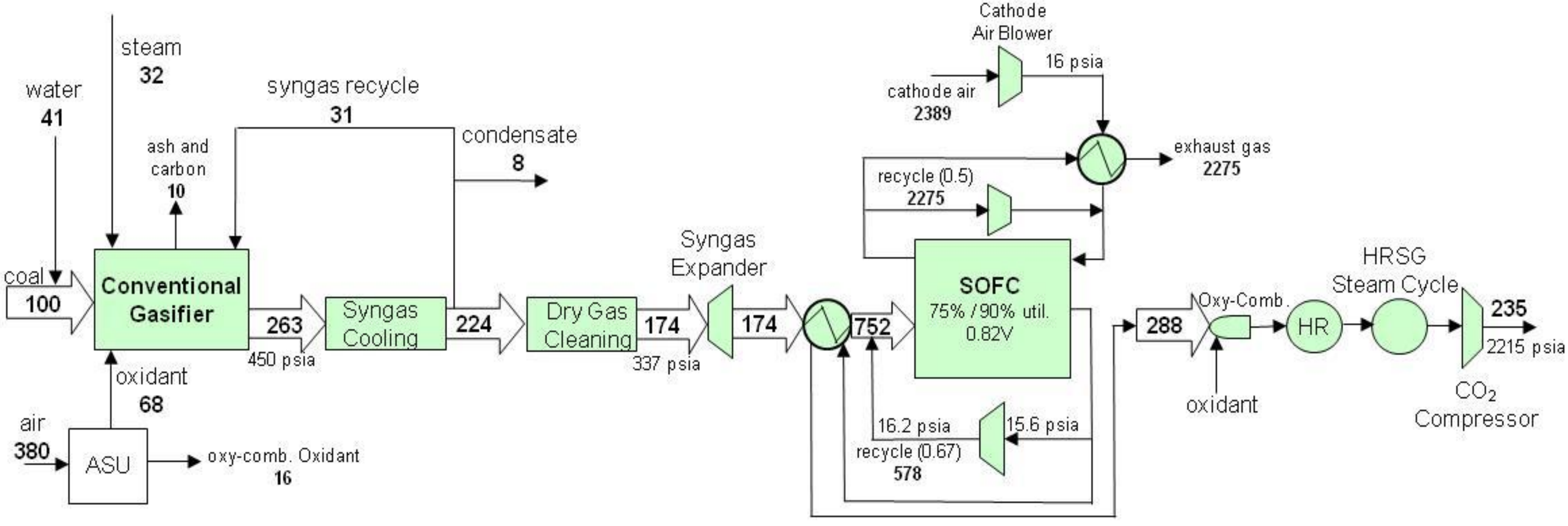
- *Each pathway begins with the atm. pressure SOFC baseline conditions*
- *30 cases used to show results from improvements in baseline conditions*

Parameter	Base	Improved
SOFC Degradation (%/1000 hrs)	1.5	0.2
Cell Overpotential (mv)	140	70
Gasifier CH_4 (conventional)	5.9%	10.2%
Gasifier CH_4 (catalytic)	30%	NA
SOFC Stack Cost (Atm.) ($/kW)	296	268
SOFC Stack Cost (Pressure) ($/kW)	442	414
Inverter Efficiency	97%	98%

Results: Data Reported

- Process Block Flow Diagram and Stream Table
- Power Summary
- Mass Flow Diagram
- Energy Flow Diagram
- HP and LP-Steam Balances
- Water Balance
- Carbon Balance
- Sulfur Balance
- Air Emissions
- Capital Cost Breakdown
- Owner's Cost Breakdown
- First-year COE Breakdown

IGFC Mass Flow Balance Example



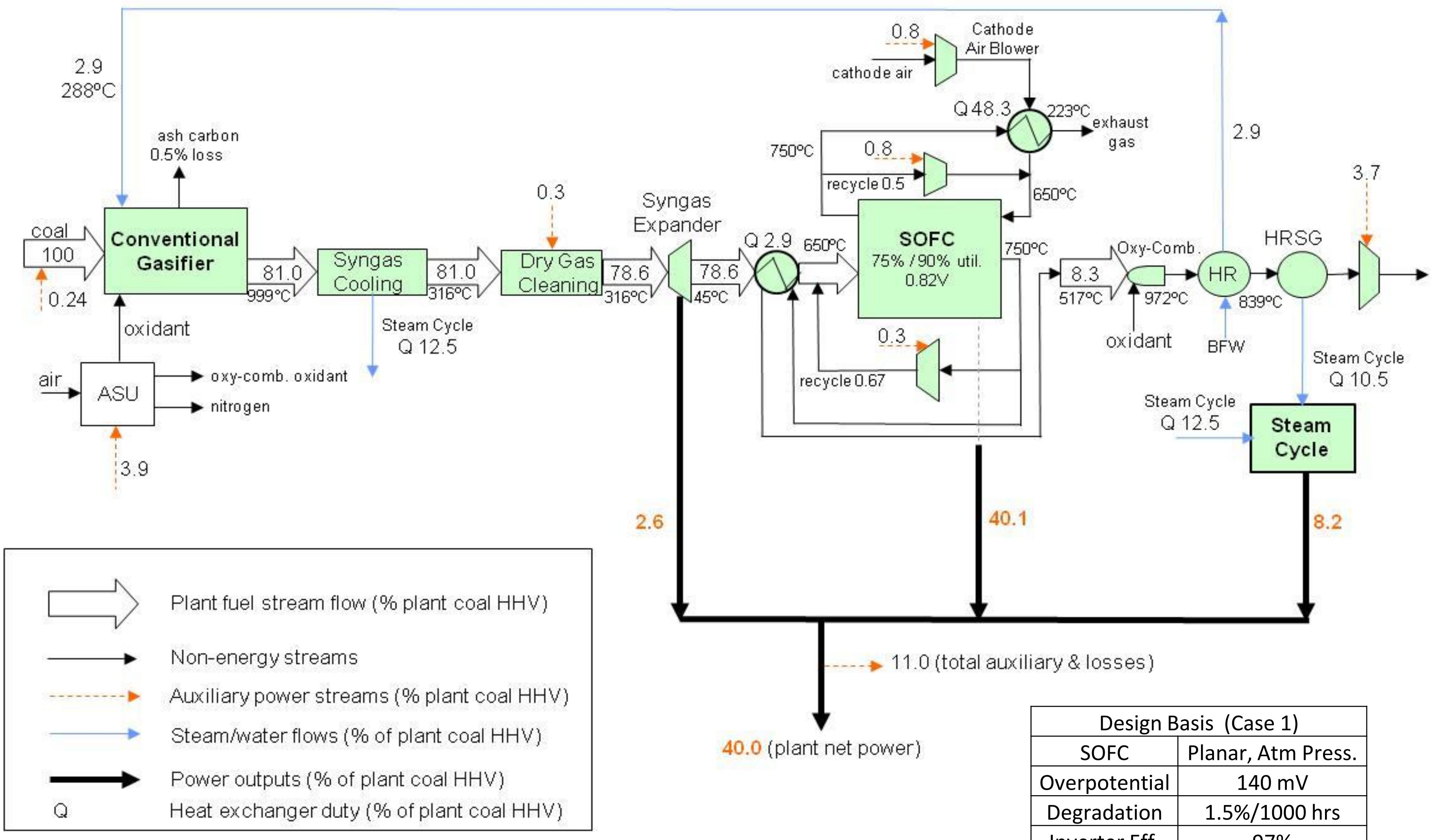
*Coal feed: ILL #6 as received

Main fuel stream mass flows (% of plant coal feed rate)

Non-fuel stream mass flows

Design Basis (Case 1)	
SOFC	Planar, Atm Press.
Overpotential	140 mV
Degradation	1.5%/1000 hrs
Inverter Eff.	97%
Gasifier	6% methane

IGFC Energy Flow Diagram Example

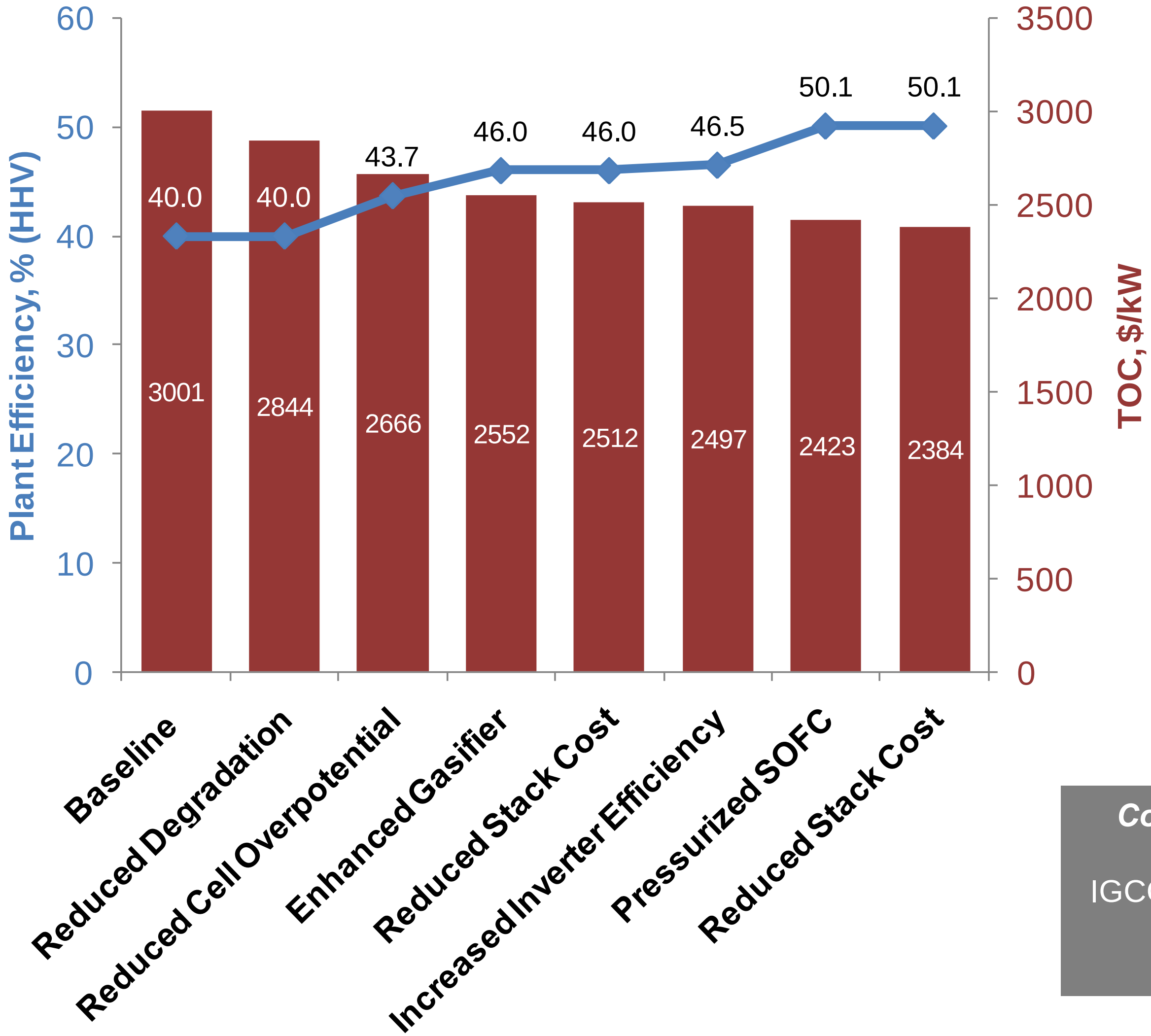


Design Basis (Case 1)	
SOFC	Planar, Atm Press.
Overpotential	140 mV
Degradation	1.5%/1000 hrs
Inverter Eff.	97%
Gasifier	6% methane

Cost Estimation

- **Consistent with Bituminous Coal Baseline Study: June 2007 $**
- **Capital Costs (total overnight cost): equipment, materials, labor, indirect construction costs, engineering, owner's costs, and contingencies**
- **Operating Costs: operating, maintenance, administrative labor; consumables; fuel; waste disposal; stack replacement cost**
- **Contingencies and Capital Charge Factor**
  – Consistent with Baseline Study
- **SOFC Stack Module Cost (Stack, enclosure, inverter)**
  – Assumes NETL Cost Target (consistent with technology developers cost estimates)
  – Cost reduction consistent with 20% reduction in stack cost
- **CO_2 transport, storage and monitoring consistent with Baseline study**
- **Natural Gas Price, \$/MMBtu: 4.0, 6.55, 12.0**

Conventional Gasifier Pathway:
Efficiency and Capital Cost



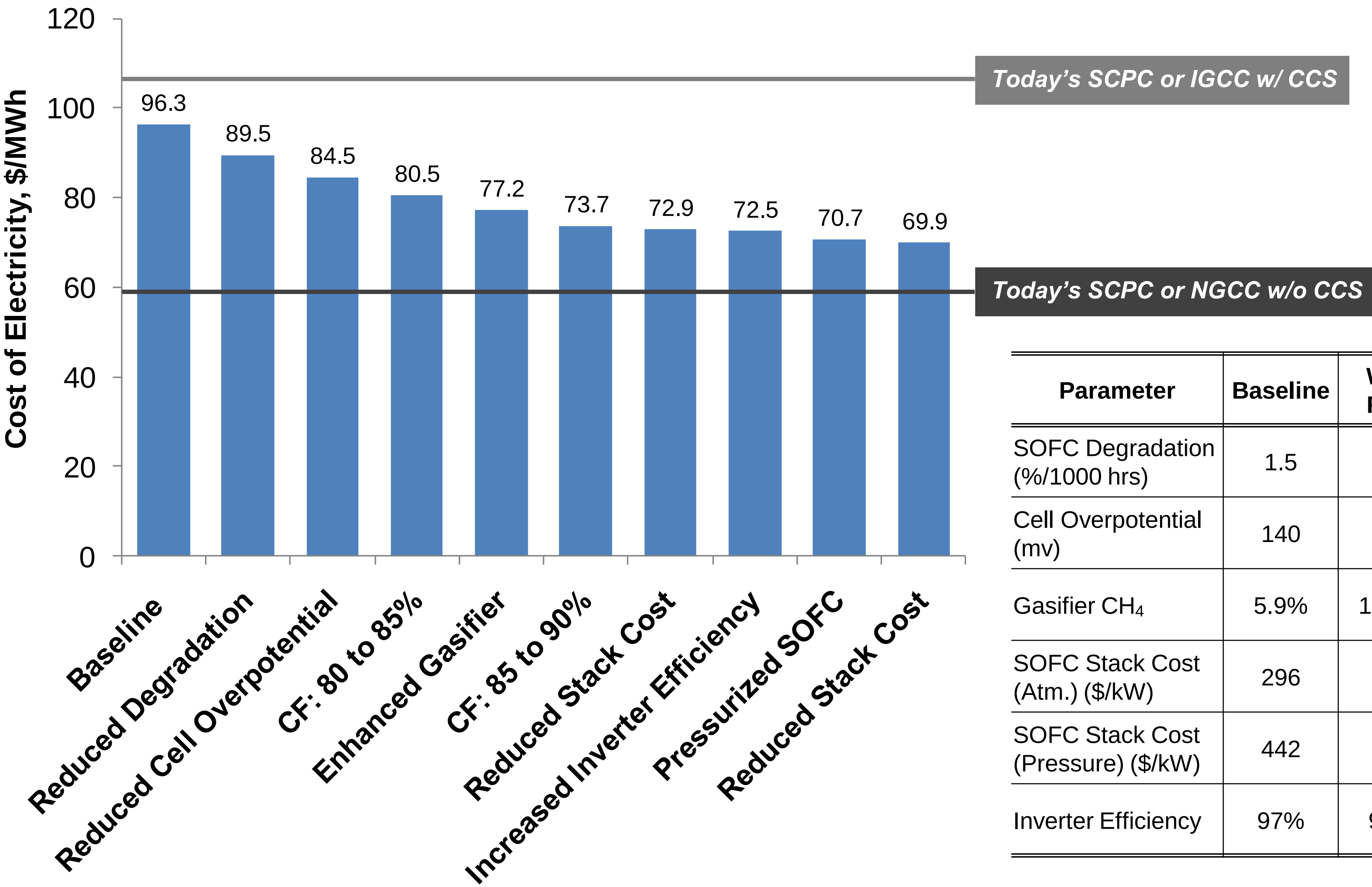
Parameter	Baseline	With R&D
SOFC Degradation (%/1000 hrs)	1.5	0.2
Cell Overpotential (mv)	140	70
Gasifier CH_4	5.9%	10.2%
SOFC Stack Cost (Atm.) ($/kW)	296	268
SOFC Stack Cost (Pressure) ($/kW)	442	414
Inverter Efficiency	97%	98%

Comparison with Today's IGCC and PC

IGCC (CoP gasifier) CCS: 31.0 %, $3466/kW
SCPC CCS: 28.4 %, $3570/kW
SCPC w/o CCS: 39.3 %, $2024/kW

SCPC = Supercritial PC

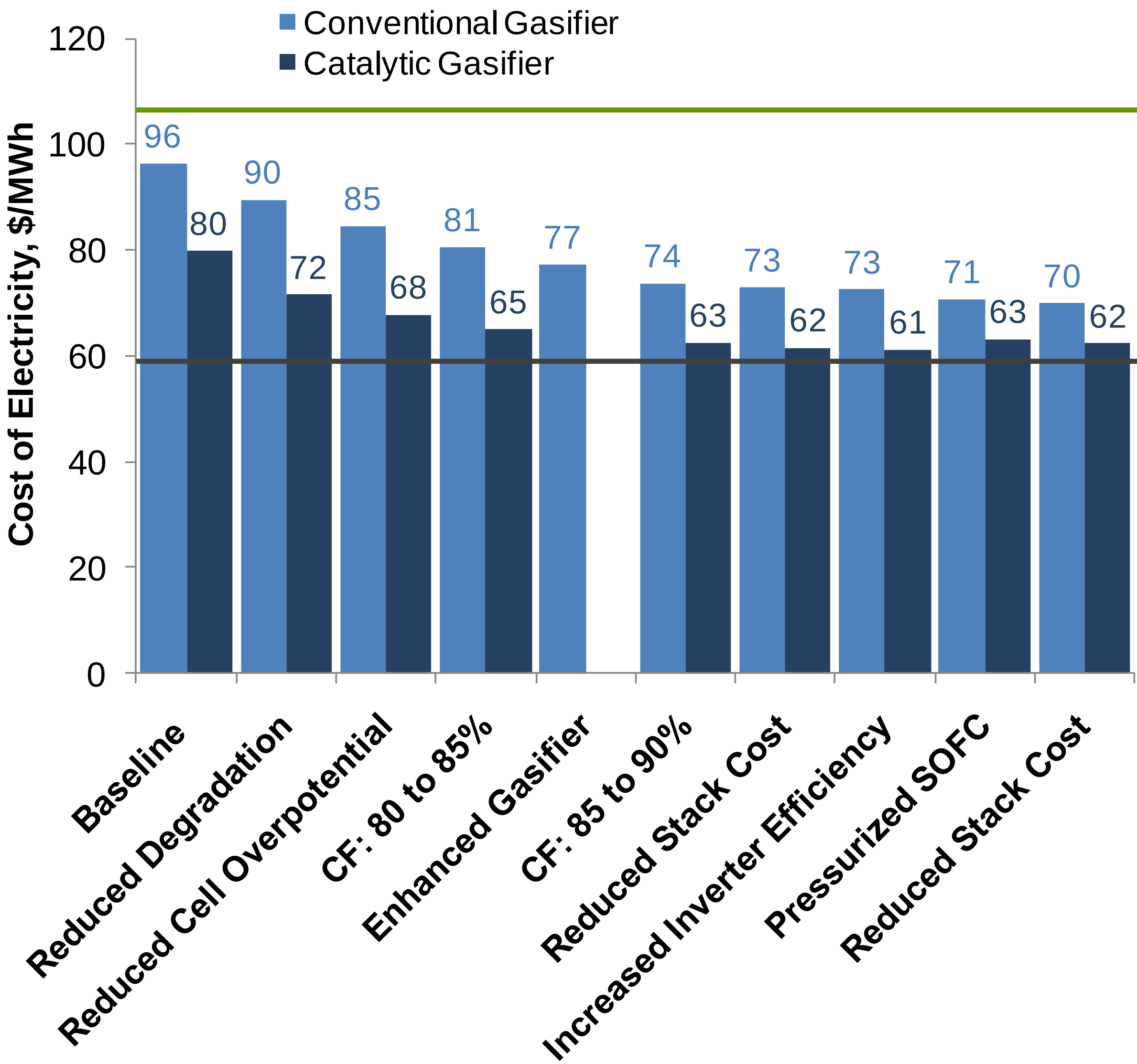
Conventional Gasifier Pathway: FY COE



Parameter	Baseline	With R&D
SOFC Degradation (%/1000 hrs)	1.5	0.2
Cell Overpotential (mv)	140	70
Gasifier CH_4	5.9%	10.2%
SOFC Stack Cost (Atm.) ($/kW)	296	268
SOFC Stack Cost (Pressure) ($/kW)	442	414
Inverter Efficiency	97%	98%

SCPC = Supercritial PC
Natural Gas Price = $6.55/MMBtu

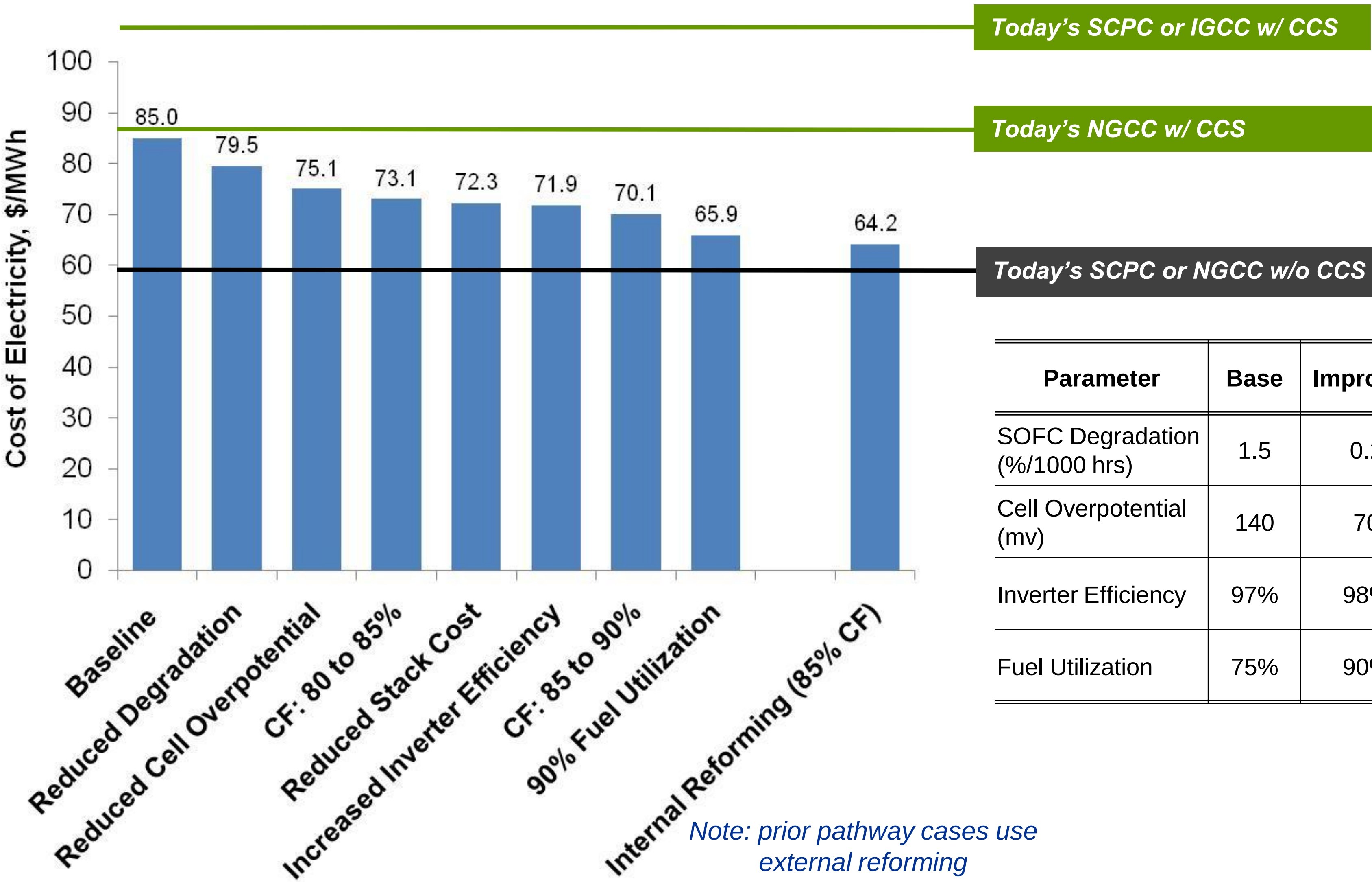
IGFC Catalytic Gasifier Pathway: FY COE



Parameter	Base	Improved
SOFC Degradation (%/1000 hrs)	1.5	0.2
Cell Overpotential (mv)	140	70
Gasifier CH_4 (conventional)	5.9%	10.2%
Gasifier CH_4 (catalytic)	30%	NA
SOFC Stack Cost (Atm.) ($/kW)	296	268
SOFC Stack Cost (Pressure) ($/kW)	442	414
Inverter Efficiency	97%	98%

NGFC Pathway FY COE

Atmospheric Pressure SOFC

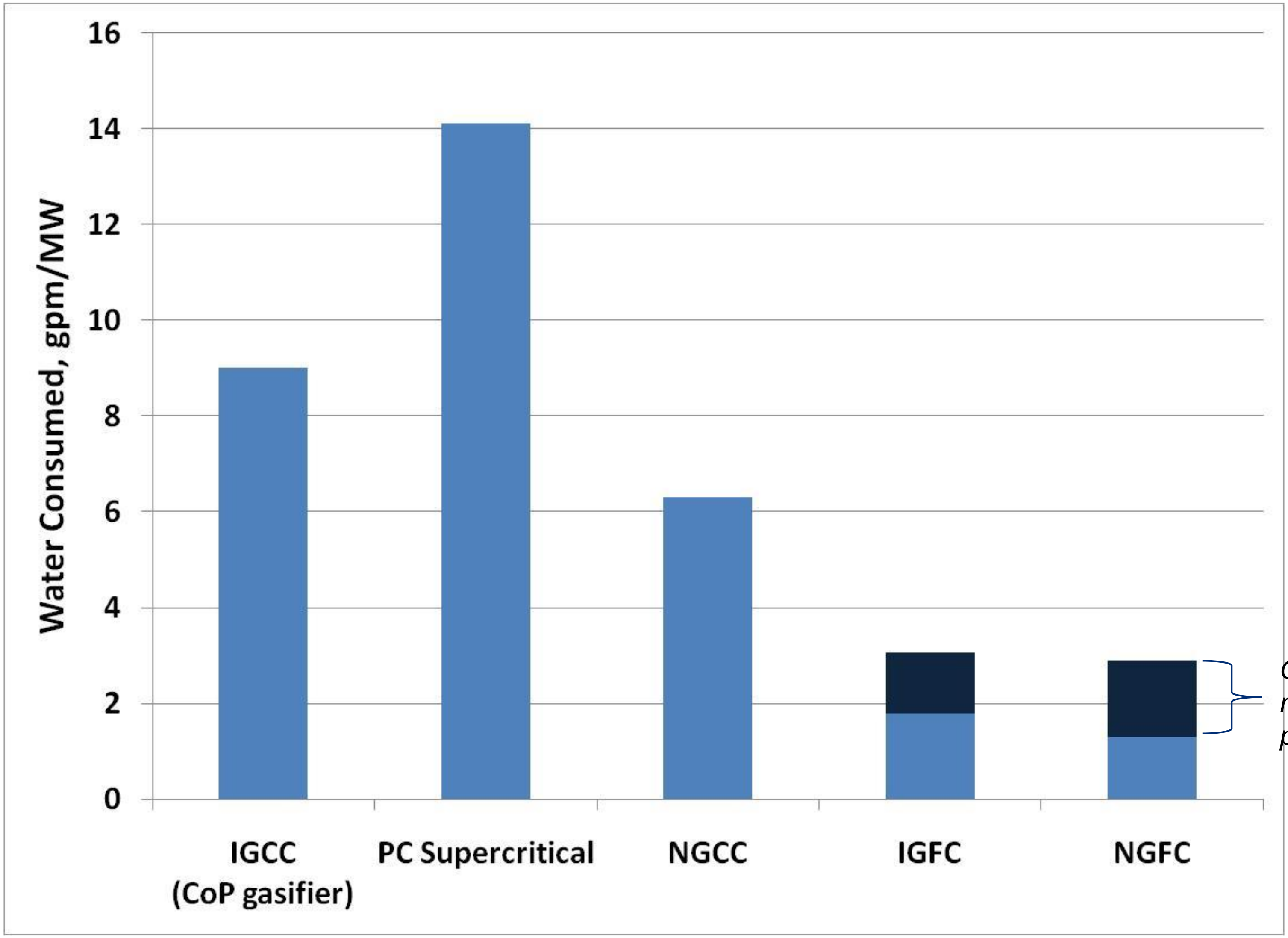


Parameter	Base	Improved
SOFC Degradation (%/1000 hrs)	1.5	0.2
Cell Overpotential (mv)	140	70
Inverter Efficiency	97%	98%
Fuel Utilization	75%	90%

SCPC = Supercritial PC

Natural Gas Price = $6.55/MMBtu

Water Consumption (with CCS)



Consumption range from pathway studies

Conclusions

- **IGFC and NGFC have significant environmental advantage over all other fossil fuel power plants**
  - Near-zero emissions including > 99% carbon capture (97% for pressurized SOFC)

- **IGFC with commercial gasifier and enhanced-commercial gasifier technology**
  - Significant performance and cost advantage over today's IGCC and PC with CCS
  - Cost comparable to today's IGCC without CCS

- **IGFC with catalytic coal gasifier and atmospheric-pressure SOFC**
  - Greatest cost benefit
  - Costs comparable to today's PC and NGCC without CCS

- **IGFC with catalytic coal gasifier and pressurized-SOFC**
  - Performance benefits over IGFC with atmospheric-pressure SOFC, but no COE benefit

Conclusions

- **Systems analysis shows benefit of**
  - Reducing cell overpotential (capital and efficiency benefit)
  - Reducing degradation (capital benefit)
  - Improving system reliability (COE benefit)
  - Internal catalytic SOFC reforming: beneficial if achieved w/o significant stack cost increase
- **Pathway study informs technology development**
  - Basis for prioritizing technology development
  - Basis for selecting test conditions (e.g. syngas composition)
- **Additional integrated system opportunities**
  - Humid gas cleaning with atmospheric-pressure SOFC
  - Advance CO_2 compression