Natural Gas-Fueled Distributed Generation SOFC Systems

Performance and Cost of Electricity

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Agenda

1	Background, Objective, and Approach
2	System Definition
3	Heat & Material Balances
4	Cost Analysis
5	Conclusions

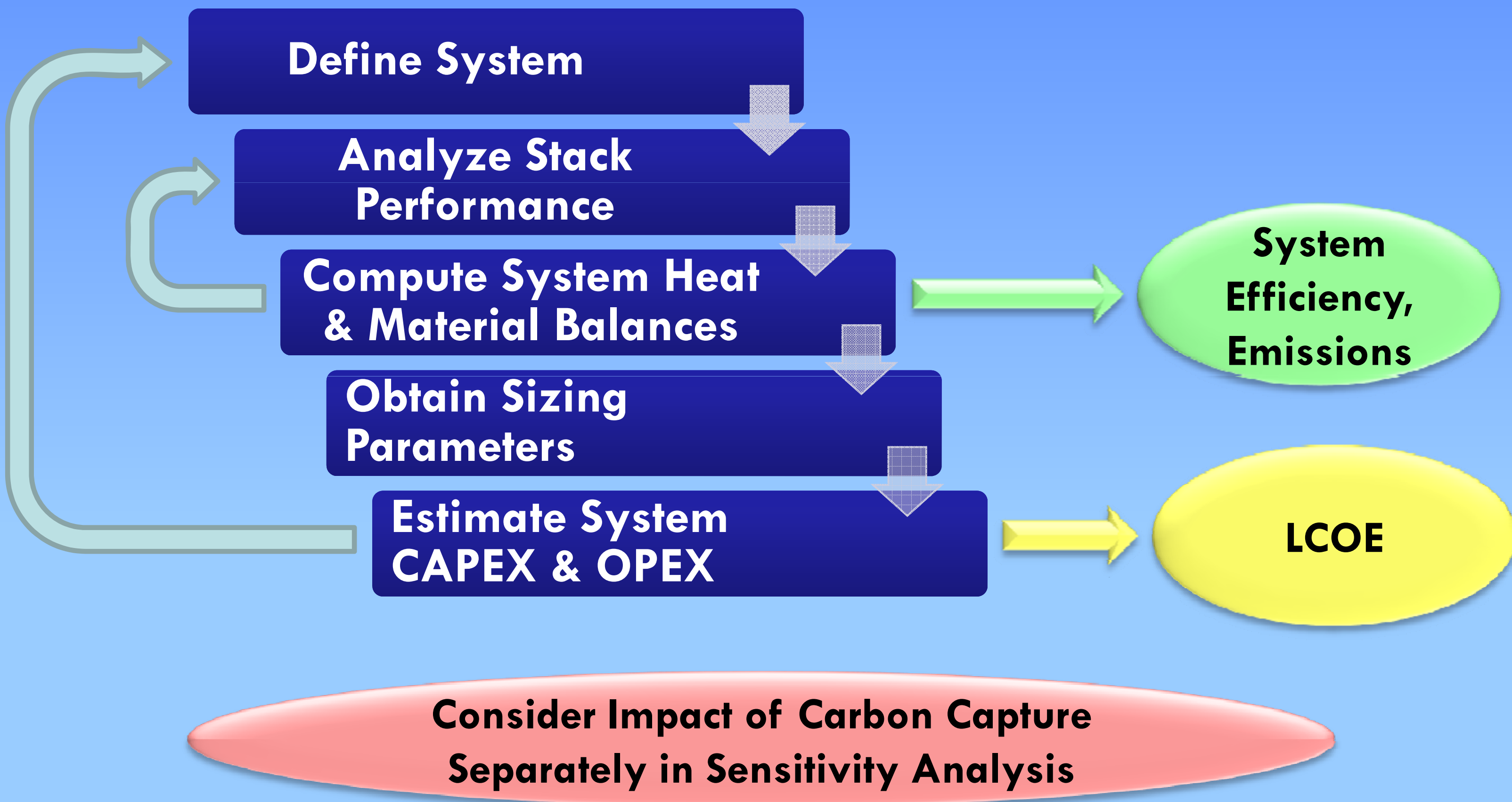
Interest in fuel cells for distributed generation has waxed and waned.

- Around 2000, interest in DG peaked:
  - Low natural gas cost (Henry Hub ~$2/MMBTU)
  - Prospect of suitable new generation technologies
- Fuel cells were thought to be a good fit:
  - Low emissions
  - High efficiency
  - Small scale
- But:
  - Fuel cells were not ready
  - Natural gas cost rose (Henry Hub >$4/MMBTU)

DOE wanted to understand the performance & cost state-of-the-art SOFC in DG applications.

- Basis for analysis:
  - 5 MW_e grid-connected system
  - SOFC stack technology available commercially 2020
  - Relevant energy cost (EIA projections)
  - Appropriate operating strategies (incl. CHP)
  - Consider cost implications of DG operation
- Based on detailed performance & cost analysis
- Allow comparison with central generation options such as IGCC and IGFC
- Consider potential impact of CCS requirements

We used our established fuel cell system model to project NG DG SOFC system performance and cost.



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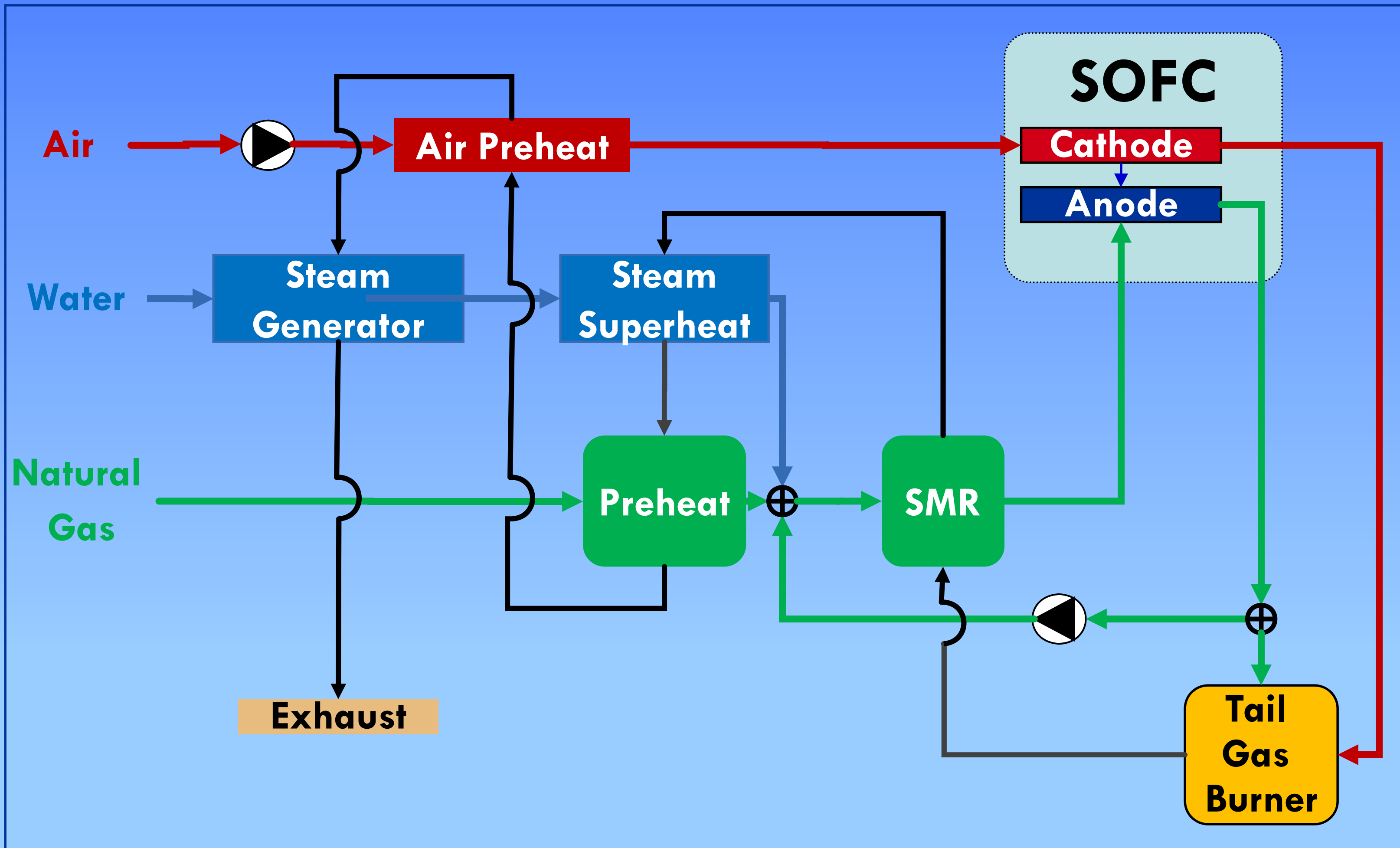
The application and scale dictates a simple and efficient flowsheet.

- Stack technology: atmospheric w/ separated flows
- Relatively small system:
  - Simple maintenance
  - Easy siting / permitting
  - Low cost
- This means:
  - Avoid wet scrubbing / adsorption processes
  - Minimize # of unit operations
  - Minimize water consumption
  - Avoid noisy components (compressors)

System Definition Process Flow Diagram



The SOFC stack assumptions used are consistent state-of-the-art stacks and with other recent studies.

- Performance consistent with state-of-the-art planar technology:
  - Polarization similar to current performance
  - Durability and temperature range consistent with DOE program targets for 2015
  - Case with small (125 cm^2) and large (2000 cm^2) cells

Key Stack Performance Characteristics			
Stack Temperature	650 – 800°C	Fuel Utilization (single pass / overall)	70% / 86%
Cell Voltage	0.83V	Anode Recycle	60%
Cell Current Density	0.50 A/cm^2	Cathode Stoichiometry	2.86

Several carbon capture options are technically possible.

- Sorbent capture from exhaust
- Water gas shift + capture from syngas
- Oxyfuel combustion of anode exhaust + whole gas capture

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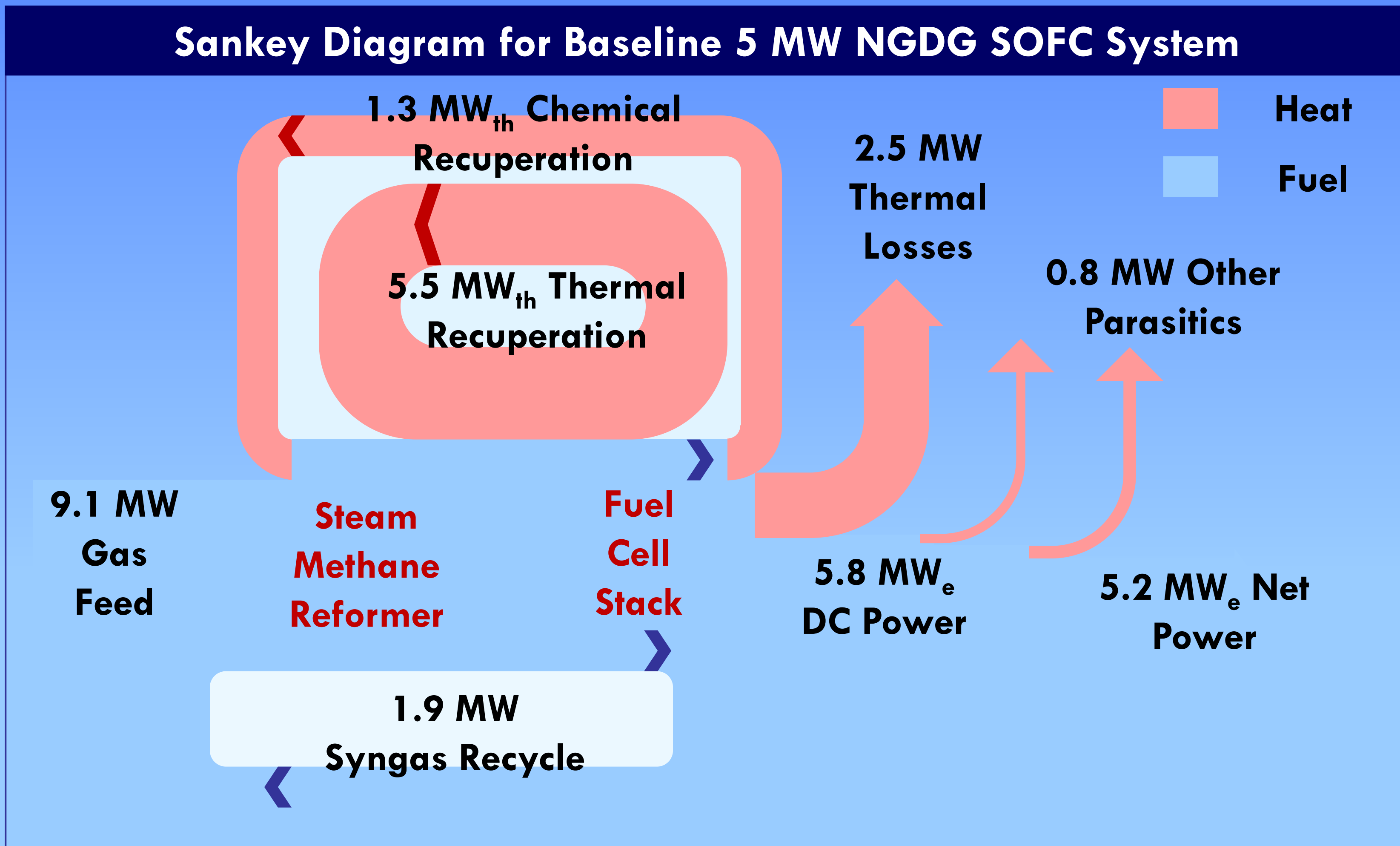
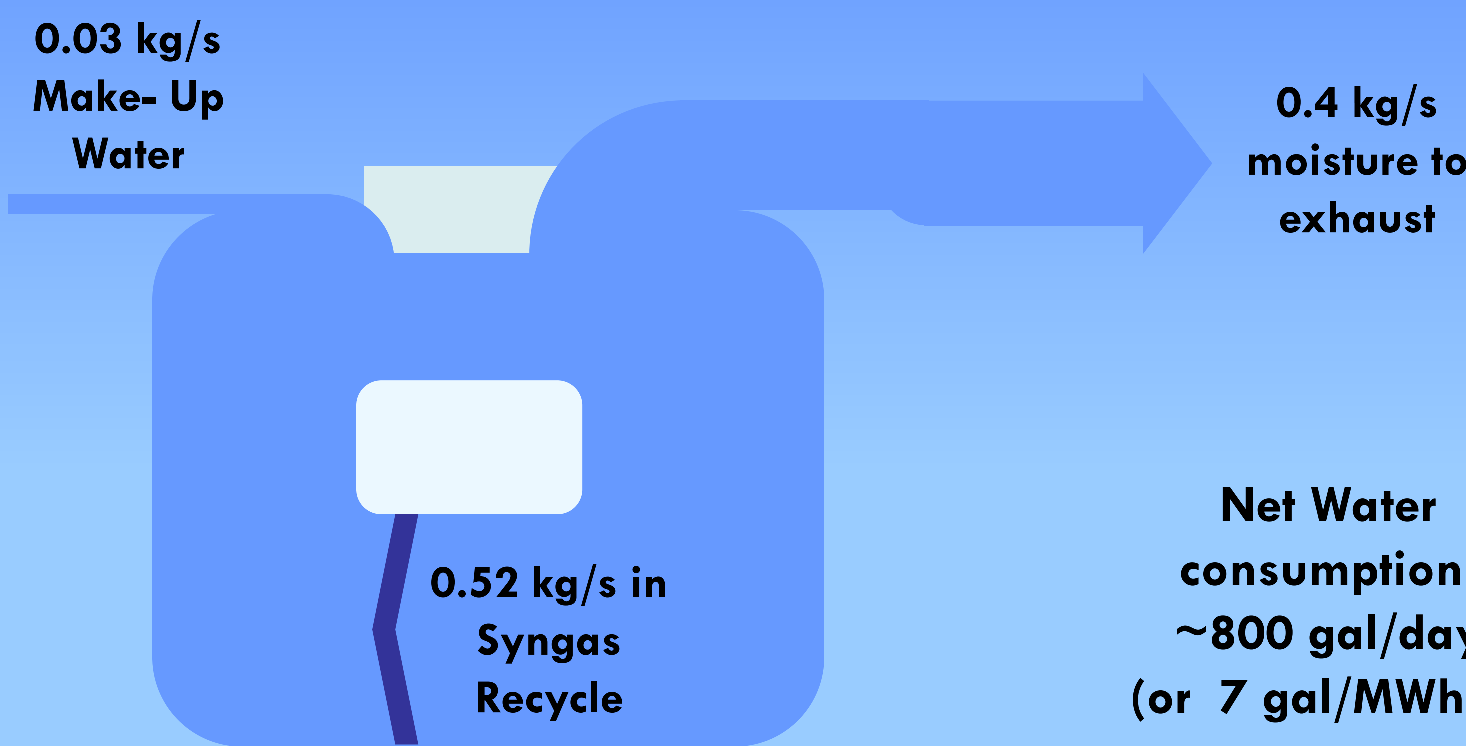
To achieve high efficiency, significant recuperation is necessary.



Syngas recycle is critical to the system water balance: it provides steam for the reformer.

Water Management (5 MW System)



Net Water consumption: ~800 gal/day (or 7 gal/MWh$_{net}$)

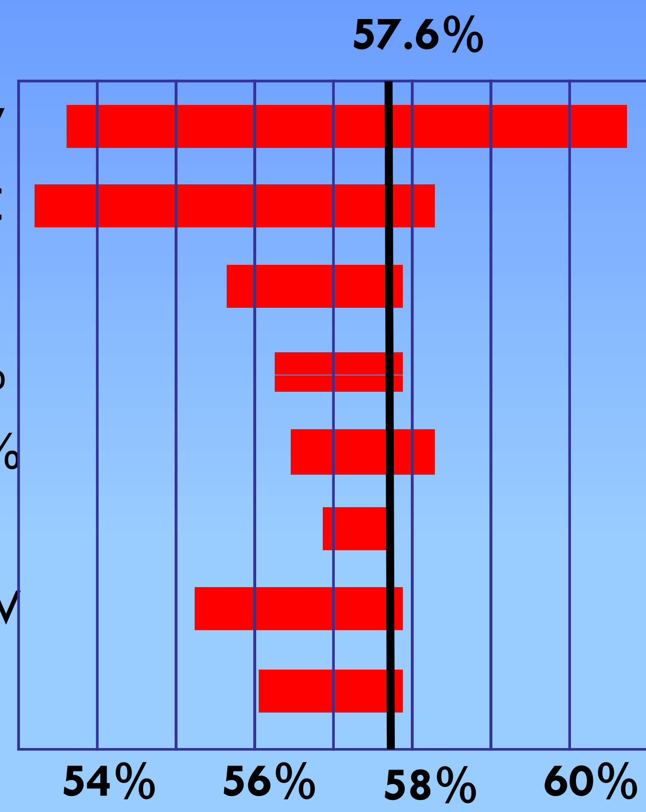
~58% efficiency (HHV) is achievable in simple-cycle configuration.

System Performance (5 MW DG System)		
Fuel Cell Stack	Fuel Utilization (single pass, overall)	70% / 86%
	Anode Recycle	60%
	Cathode Stoichiometry	2.86
	Stack Temperature	650 – 800°C
	Cell Voltage	0.83 V
	Fuel Cell Gross Power	5.7 MW
Reformer	Steam / Carbon Ratio	3
	Methane Slip	7%
	Water Use	800 gpd
BoP	Blower Power	230kW
	Other Parasitic Loads	50 kW
System	Exhaust Temperature	315 °C
	System Efficiency (HHV Basis)	57.6%

Cell voltage and stack temperature rise have the greatest impact on efficiency.

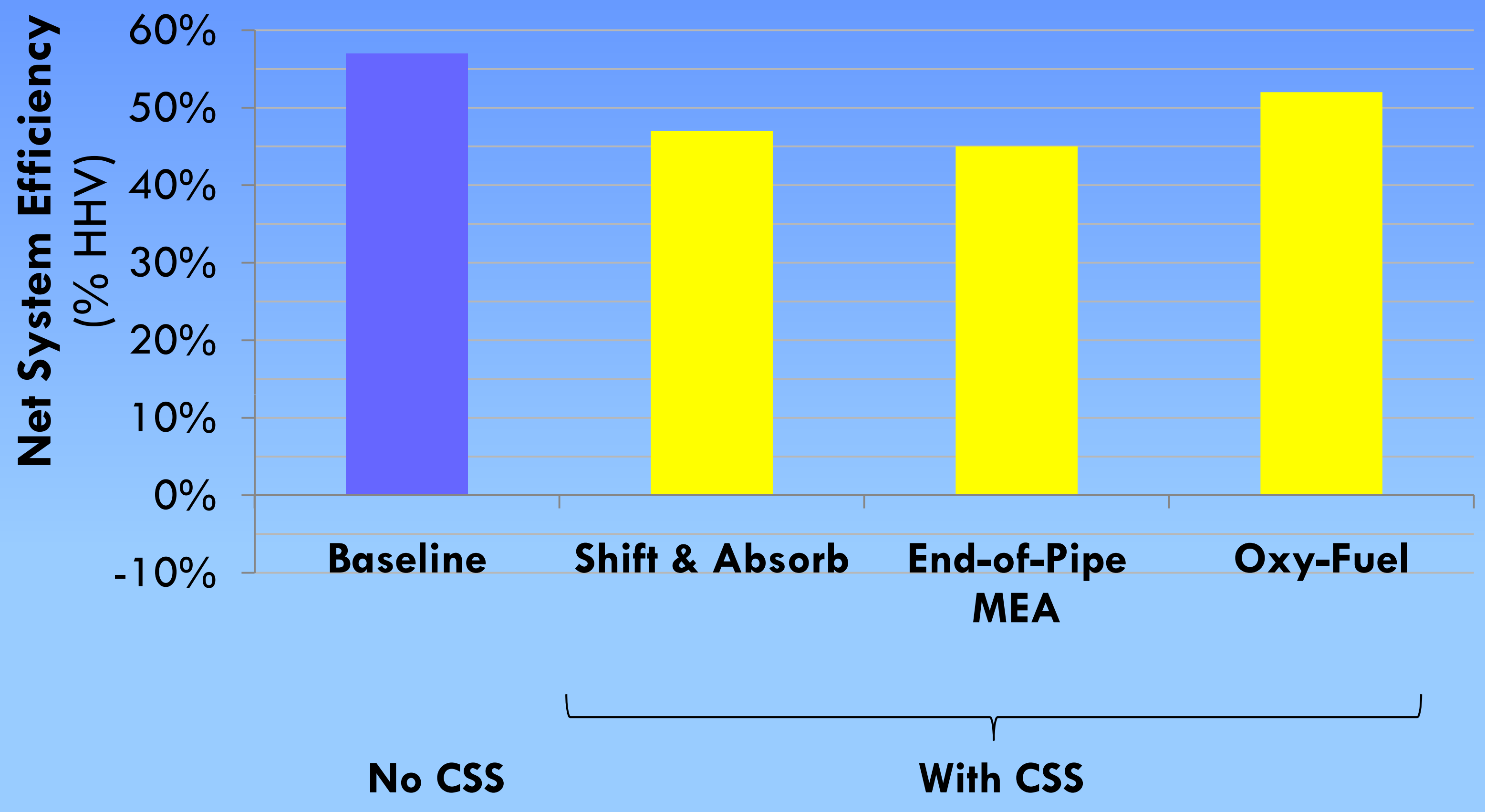
Sensitivity of System Efficiency (5 MW DG System)

Fuel Cell Stack	Cell Voltage	0.77 0.85 V
	Stack ΔT	75 – 200°C
	Anode Recycle	40 - 75%
	Fuel Utilization	60 %– 85%
	Stack Heat Loss	50 %– 200%
Reformer	Steam / Carbon Ratio	2 – 3.5
BoP	Other Parasitic Loads	25 – 250 kW
	Blower Efficiency	50%- 85%



Oxyfuel combustion & whole anode gas capture likely presents the most realistic CCS option.

Impact of CCS on Efficiency (Maximum 30 gCO_2/kWh Emissions)



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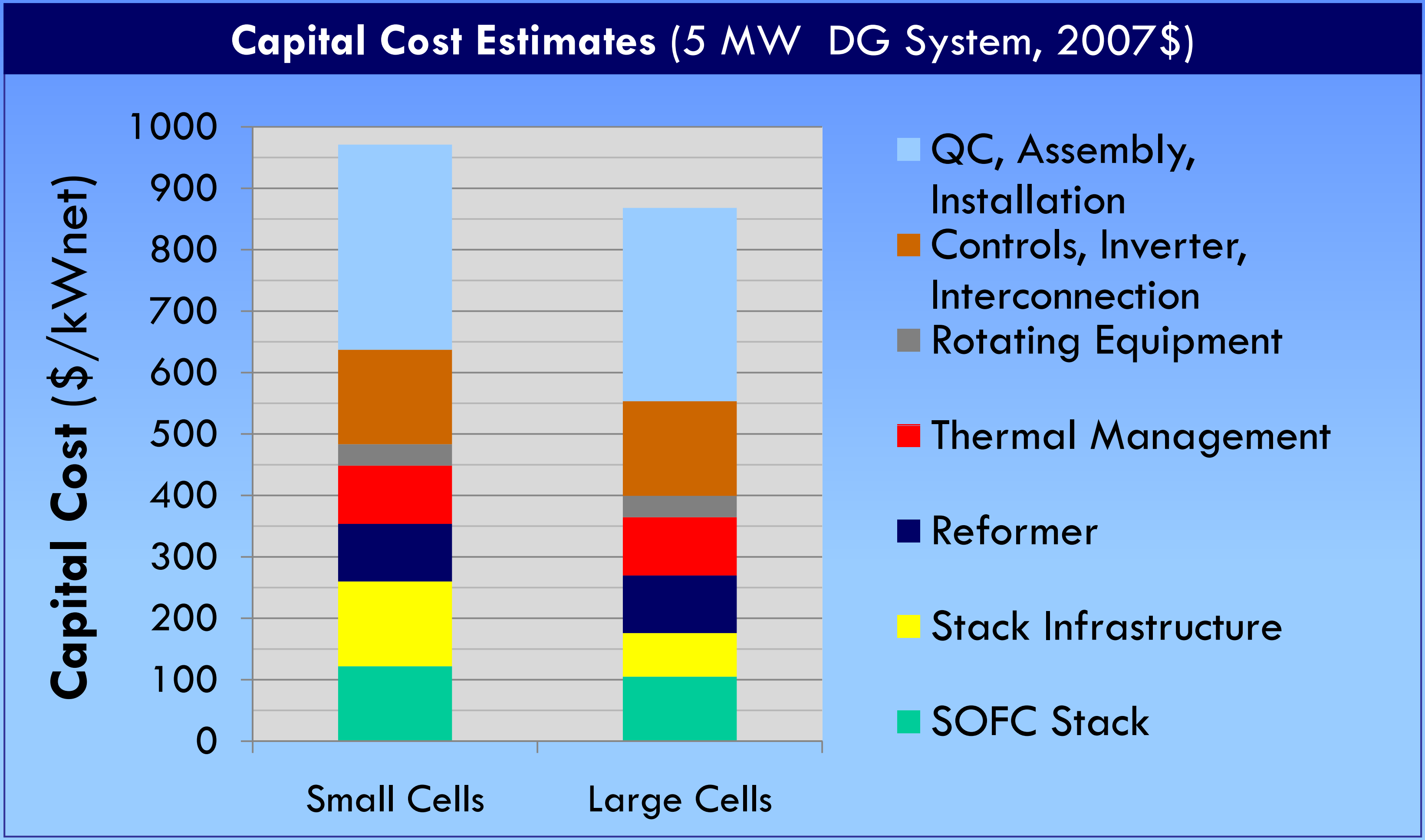
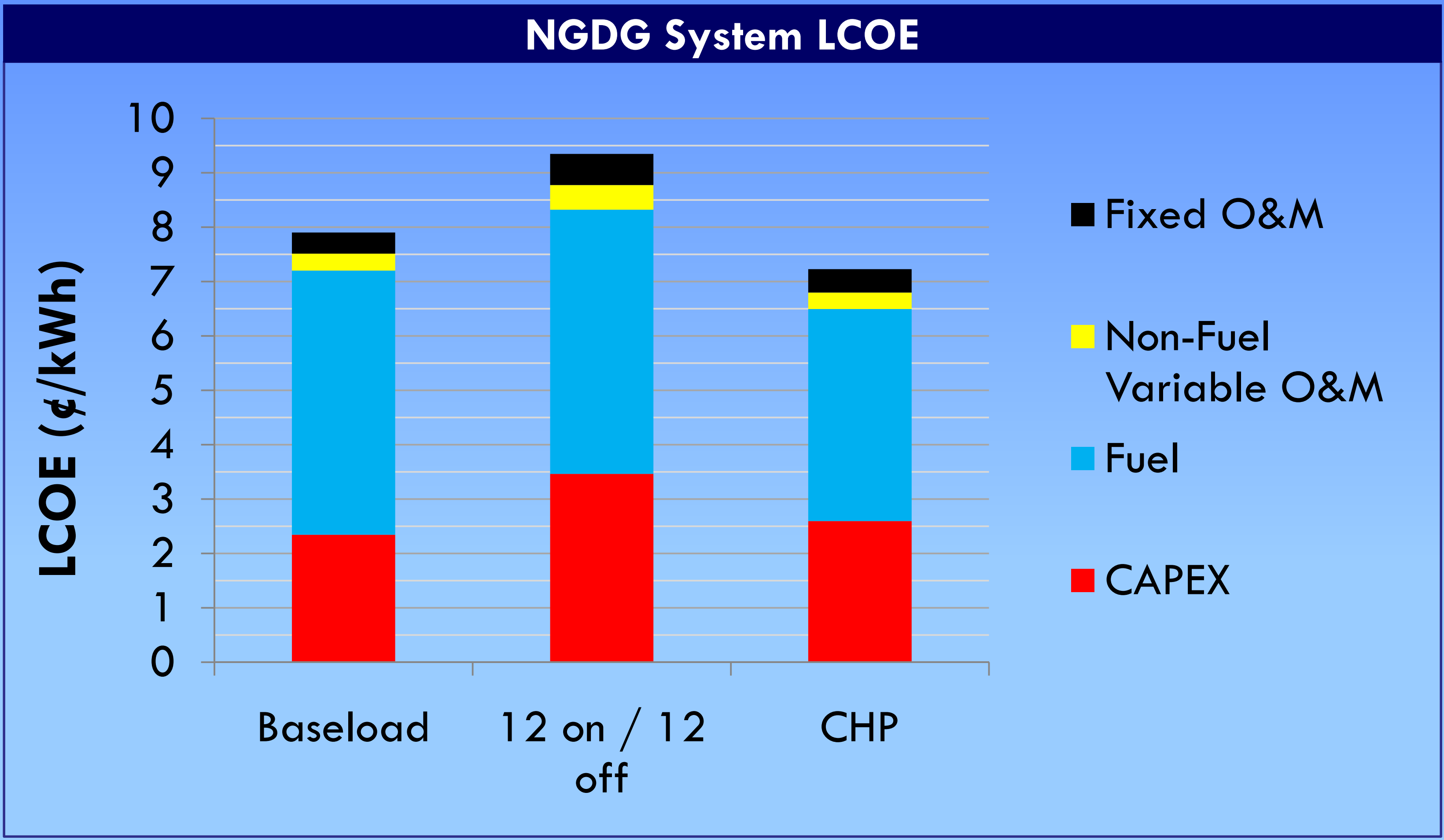
The cost analysis followed a well-established methodology, building on several previous studies.

- Bottom-up activity-based stack cost analysis
- BoP equipment costs via scaling from quotes
- Costs were escalated to 2007 based on DoC's PPI
- A uniform 42.5% installation factor was used

The cost analysis indicates that installed CAPEX would be around $870/kW

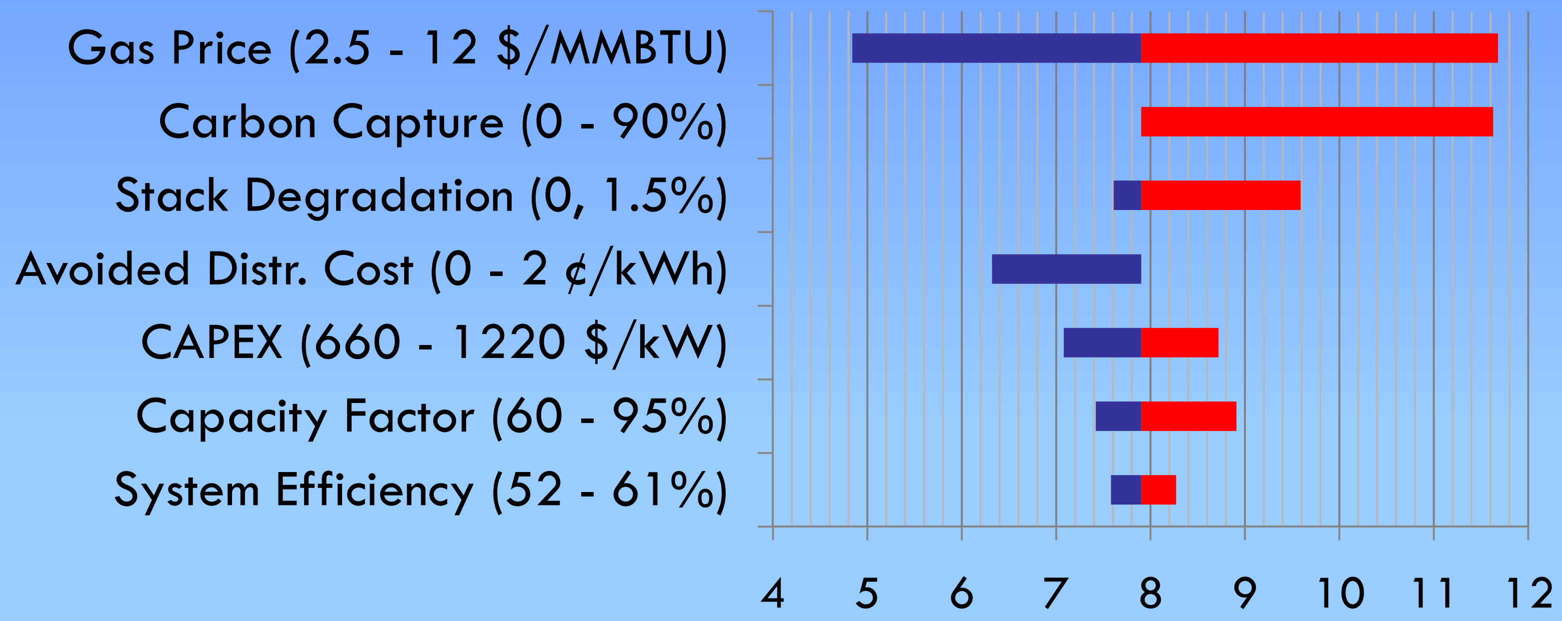


The LCOE from NGDG SOFC systems ranges from 7 to 9.5 cents/kWh.



Gas price, carbon capture, and stack degradation most strongly impact LCOE for DG systems.

Sensitivity of LCOE (5 MW DG System)



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Technically spectacular NGDG SOFC systems appear feasible…

- State-of-the-art SOFC enable highly efficient, simple-cycle, systems:
  - ~58% efficiency (HHV basis)
  - Water use ~7 gal/MWh
  - CO_2 emissions 340 g/kWh (CCS technically possible)
  - Very low noise, local air emissions
- But degradation should be reduced to ~0.5%/1,000 hrs or less

… and in some selected market segments their cost could be attractive.

- In high-volume production:
  - CAPEX ~$870/kW (2007$)
  - LCOE 7.2 – 9.3 ¢/kWh
  - Strong function of gas price, capacity factor
- This range is likely competitive in selected market segments (CHP, incentives, local conditions)
- It is not broadly competitive with central generation
- If deep carbon reductions are required(>60%):
  - CCS would be required
  - NG DG would likely be uncompetitive

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Thank You!