NATURAL GAS FUEL PROCESSING EXPERIENCE AND ISSUES

SECA Core Technology Program (CTP) workshop

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OVERVIEW

- ***Natural Gas Composition***
- ***Issues and Current Approach***
- ***Internal Reforming***
- ***Recommendation for Core Technology Program***

US PIPELINE NATURAL GAS COMPOSITION REPRESENTING 90% OF THE US SUPPLY

PROPERTY	RANGE/LIMITS
Composition	
Methane, vol%	80 – 100
Ethane, vol%	0 – 10
Propane,* vol%	0 – 3
Pentane, vol%	0 – 1.25
Unsaturated Hydrocarbons	None
Inert Gases	0 – 5
- Nitrogen, vol%	0 – 3
- Carbon Dioxide, vol%	0 – 3
Oxygen, vol%	0 – 0.2*
Impurities	
Total Sulfur, ppmv	0 – 12
- Odorants (thiophenes, mercaptans, etc.)	0 – 12
- H_2S	0 – 1.0
- COS	0 – 2.0
- Halogens (Cl, etc.)	None
Heating Value, Range	
- LHV, Btu/scf	870 – 1000
- HHV, Btu/scf	970 – 1100

* Peak showing may be higher (0.5-10%)

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ODORANT COMPOSITION IN US PIPELINE NATURAL GAS

Natural Gas Odorant Blend	All Mercaptan Blend	Mercaptan/Alkyl Sulfide Blend	Thiophene/ Mercaptan Blend	Thiophene (99.9%)
Natural Gas Odorant Market Share, %	40 - 55	40 - 55	5	<1
Composition Breakdown		Sulfide Content is Usually 20-50% but can be 70-90% in Limited Areas	Thiophene Content is Usually 30-50% but can be ~70% in Limited Areas	

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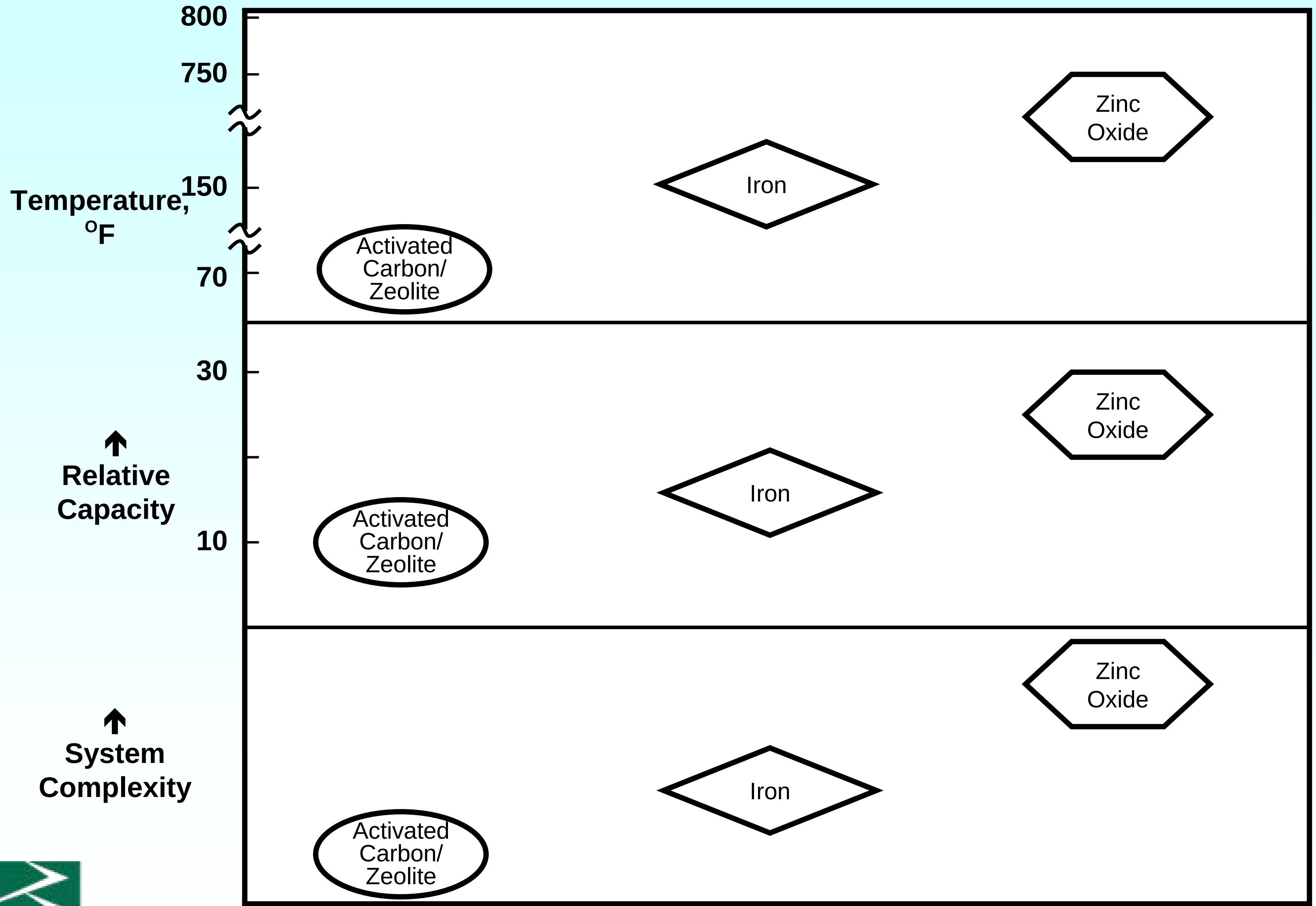
REQUIREMENTS FOR NATURAL GAS OPERATION

Component in Natural Gas	Consideration	Approach
CH_4	Carbon Formation During heat-up	Steam addition Non-Catalytic Surfaces Carbon Resistance
HHC	Carbon Formation	Pre-Catalyst Reforming
Diluents: N_2; CO_2	Parasitic Losses	-
Contaminants		
- H_2S	Catalyst Poisoning Hardware Corrosion	Clean-up to subppm level (Sulfur Tolerant Anode)
- Organic Sulfur	Organic Sulfur	May require HDS
- Oxygen	Uncontrolled Heat Release, Corrosion	Pre-oxidizer (pt-Catalyst)

ROOM TEMPERATURE HIGH CAPACITY SORBENTS ARE DESIRABLE



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TEST SET-UP FOR NATURAL GAS CLEAN-UP

Room Temperature System

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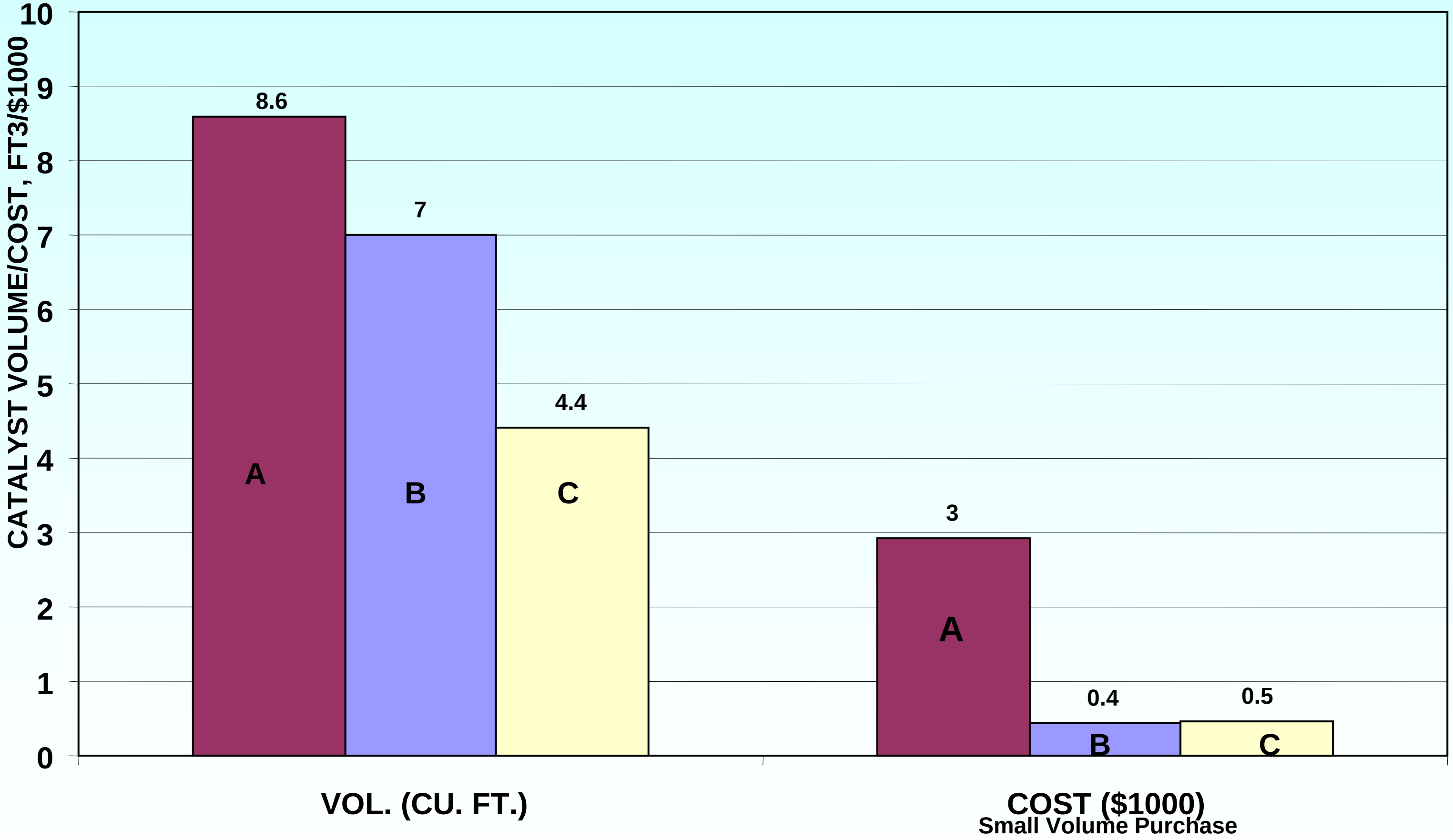
RELATIVE AMOUNTS AND COSTS OF SORBENTS USED TO TREAT 1.0 MMSCF OF PIPELINE NATURAL GAS AT FCE DANBURY POWER PLANT



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REACTIONS FOR NATURAL GAS -SOFC

OPTION	REACTIONS
Steam Reforming	$CH_4 + 2H_2O \xrightarrow{+Q} CO_2 + 4H_2$
Partial Oxidation	$CH_4 + O_2 \xrightarrow{-Q} CO_2 + 2H_2$
Direct Oxidation	CH_4 - - - - - - - - - - - - -

$$\xrightarrow{+O^{=}} CO_2 + H_2O + e^{-}$$

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OPTIONS FOR NATURAL GAS PROCESSING FOR USE IN SOFC

PROCESS	BENEFIT	TRADE-OFF CONSIDERATION
Steam Reforming	High Efficiency	Steam Management
Partial Oxidation	Rapid Response	Reduction in Efficiency NO_x Formation
Direct Oxidation	Simple System	Carbon Formation

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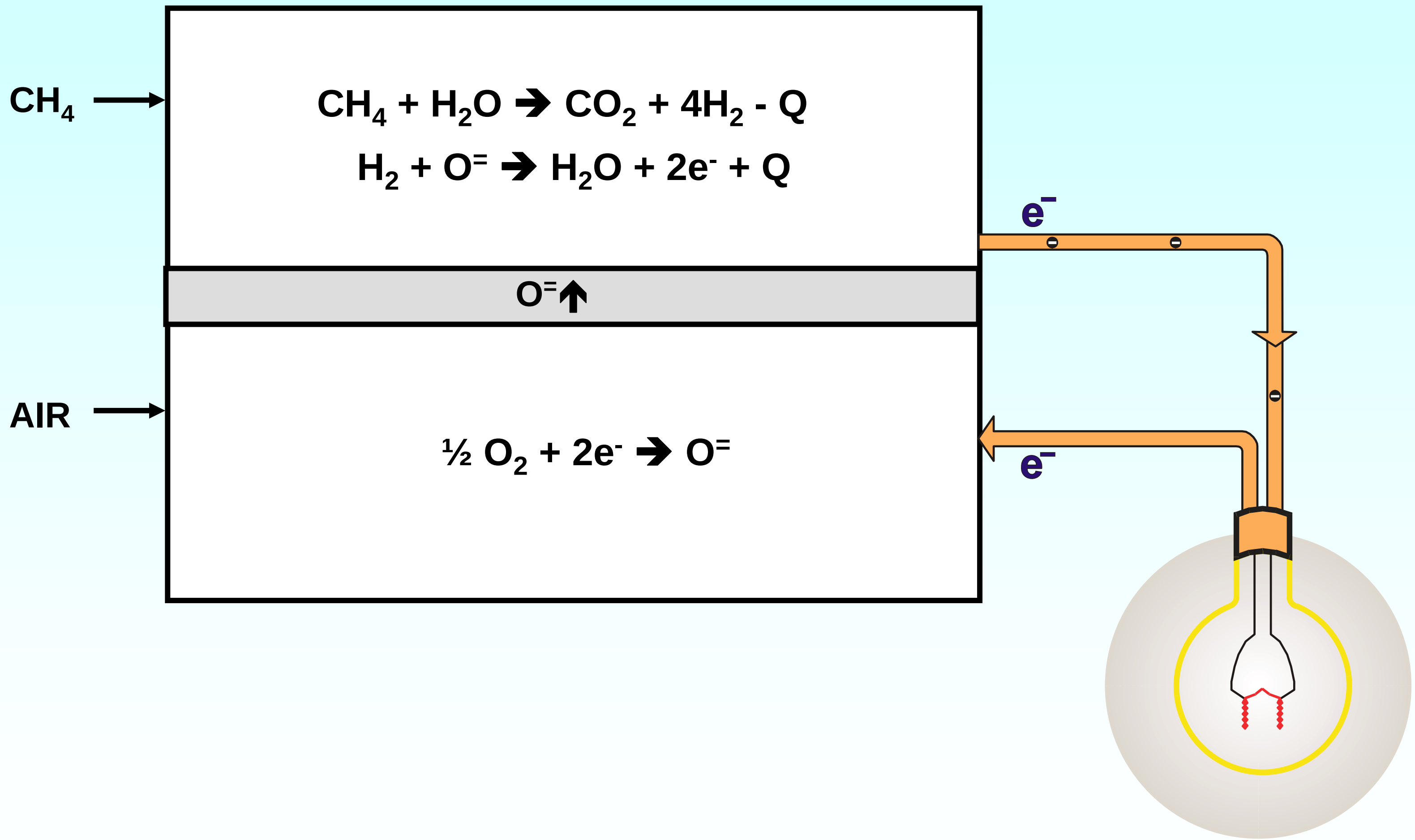
INTERNAL REFORMING IN SOFC



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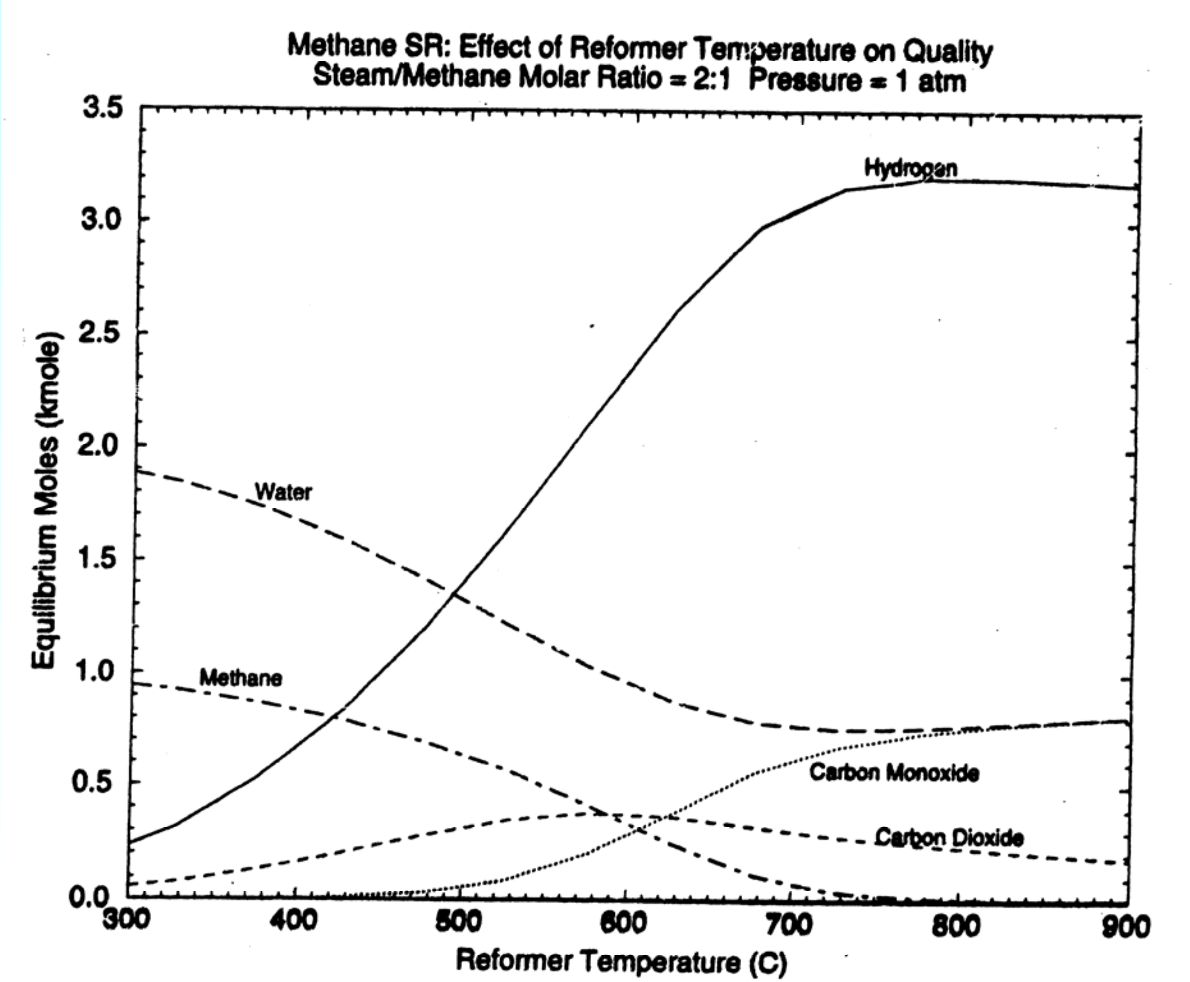
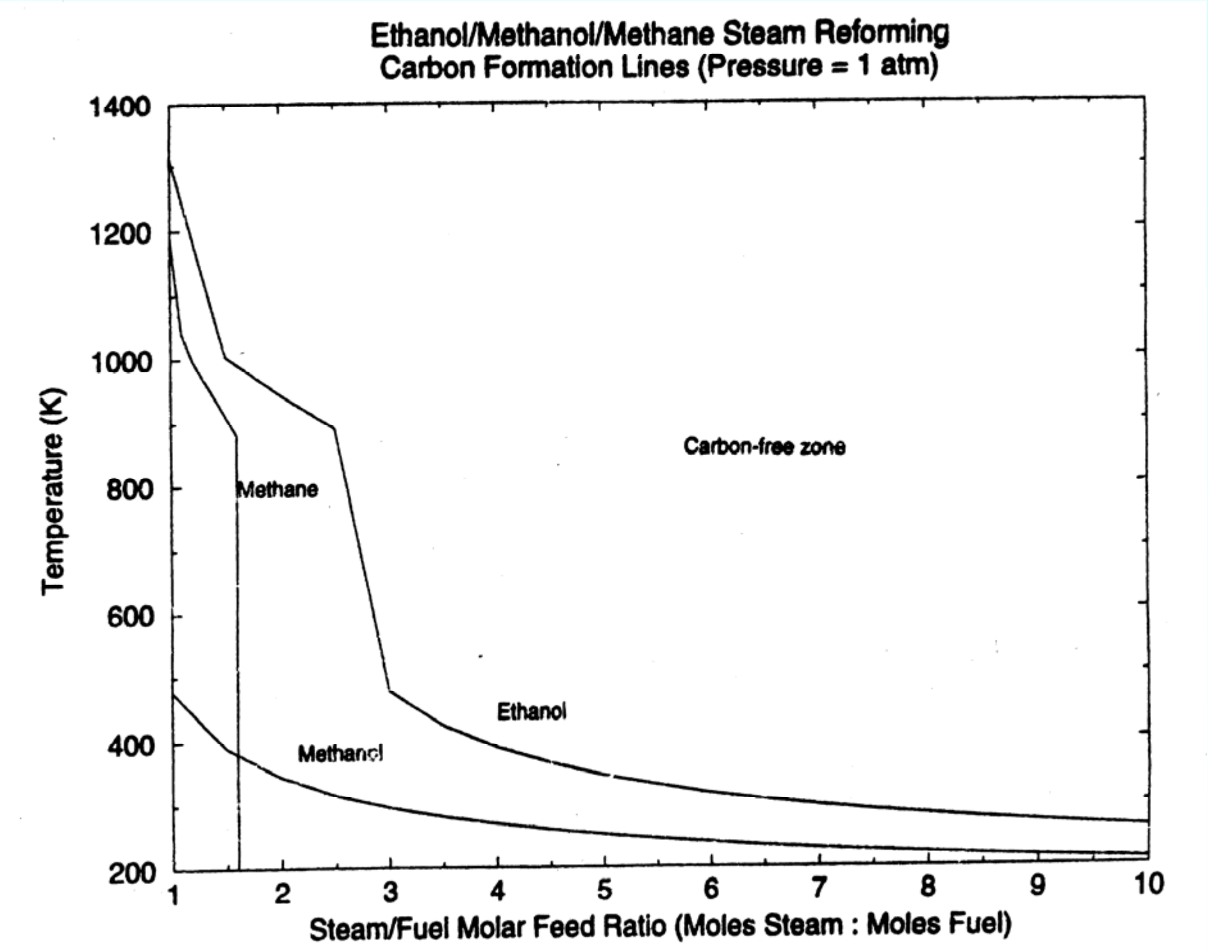
WHY INTERNAL REFORMING

- MAXIMIZES THERMODYNAMIC EFFICIENCY
- EFFICIENT COOLING OF FUEL CELL (DIRECT CONTACT)
- BENEFITS OF SYNERGISTIC REACTONS
- LOWER TEMPERATURE REFORMING HARDWARE
- REDUCED STEAM REQUIREMENTS
- REDUCED COOLING AIR FLOW (<2 STOICH FEASIBLE)
- POTENTIALLY COMPACT AND LOWER COST SYSTEM

EFFECT OF REFORMER TEMPERATURE ON METHANE STEAM REFORMING



CARBON FORMATION LINES FOR METHANE/METHANOL/ETHANOL STEAM REFORMING



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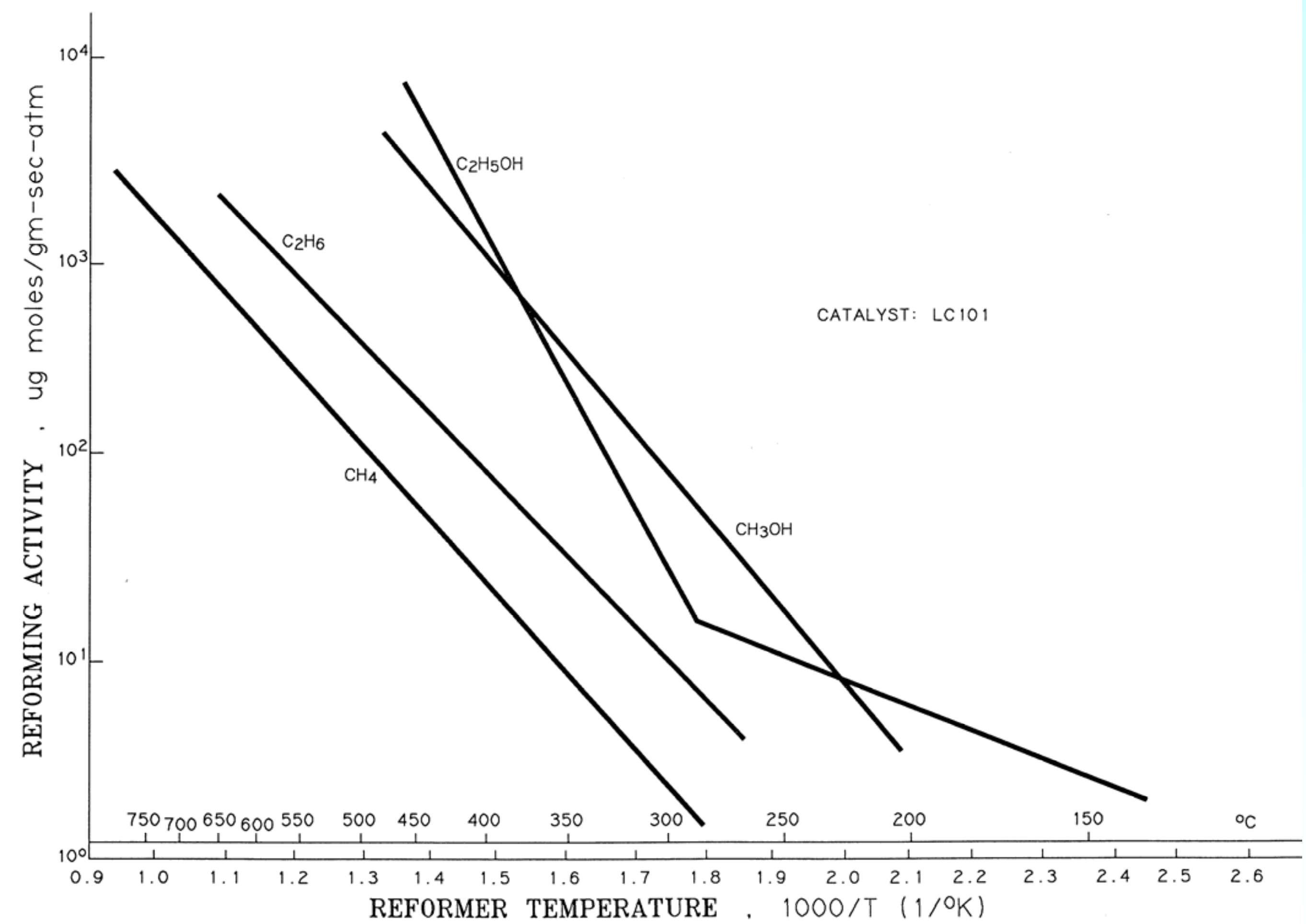
REFORMING ACTIVITY MEASURED FOR DIFFERENT FUELS



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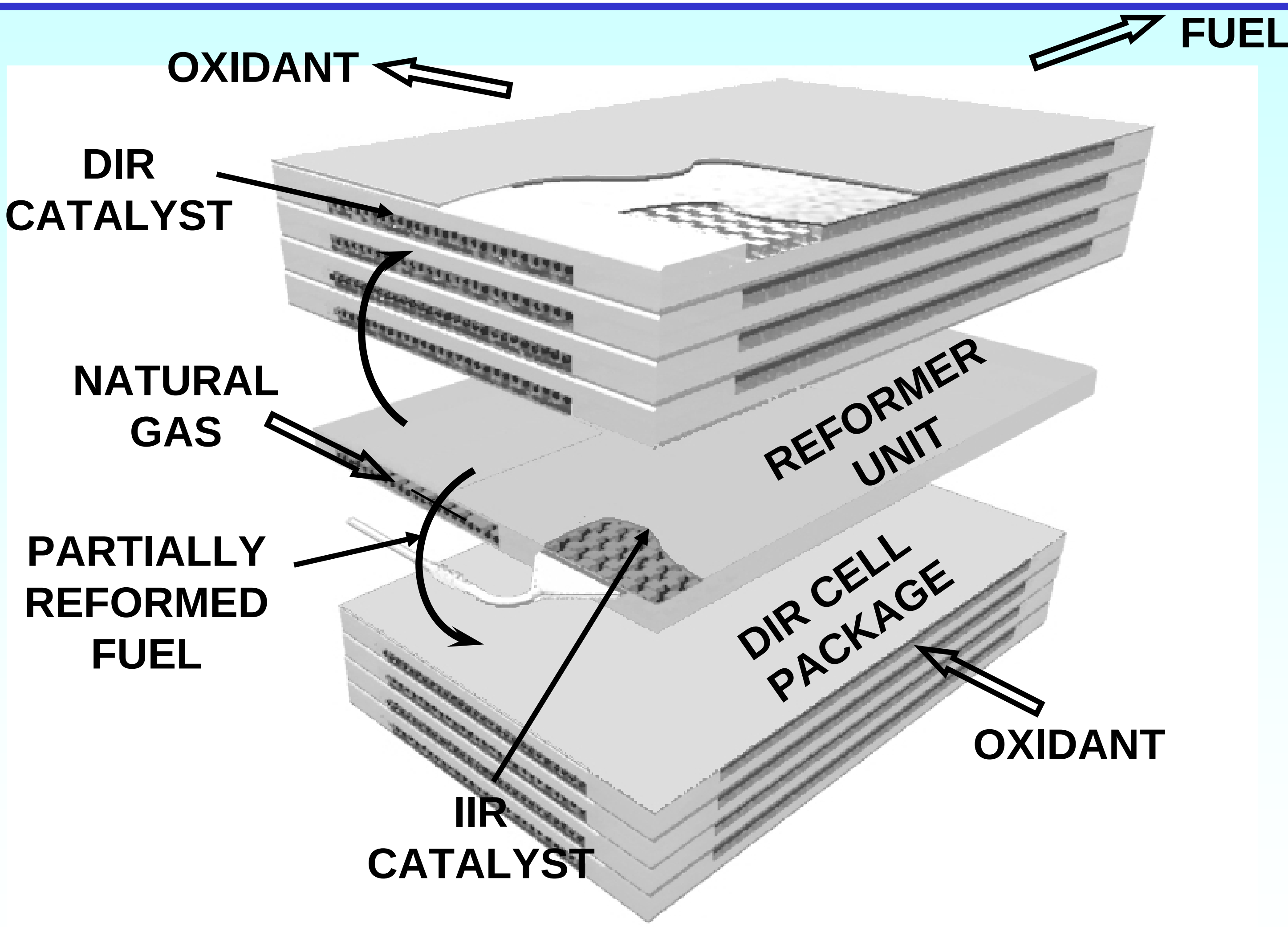
DFC® STACK CONCEPT



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10kW INDIRECT INTERNAL REFORMING PLATE

PLACED IN BETWEEN A GROUP OF CELLS IN A STACK

OVERALL DESIGN PARAMETERS AND TECHNICAL CONSIDERATIONS

PARAMETER (Operational)	TECHNICAL CONSIDERATION
Start-up Time	Method of Heat Supply, Maximum Allowable Heat Flux
Cold-start Temperature	Water Supply
Peak to Rated Power Ratio	Thermal Management, Fuel Supply at Peak Power
Response time (Rated to Peak)	Control System Response Rates, Lag in Response Due to Reformer, Boiler and HEX
Time at Peak	Thermal Management (Hot Spots)
Water Self-Sufficiency	Water Recovery
Emissions	Burner Efficiency
System Life	Catalyst Life
Reliability	Simplicity
Safety	Shock Resistance, Hot Spots
Serviceability	Simplicity, Accessibility

(Continue)

OVERALL DESIGN PARAMETERS AND TECHNICAL CONSIDERATIONS (Cont'd)

PARAMETER	TECHNICAL CONSIDERATION
Packaging (ft^3/kW, lbs/kW peak)	Component Sizes, Interconnection, Weight, Simplicity
Overall Efficiency (Rated, Avg.)	Thermal Losses, Parasitic Power, Idle Fuel Consumptions
Cost ($/kW, Rated)	Component Costs, Assembly and Installation costs
Repairs and Maintenance Costs	Simplicity, Reliability, Serviceability, Variable Costs

RECOMMENDATIONS FOR CORE TECHNOLOGY PROGRAM

AREA	OPPORTUNITY/BENEFIT
Sulfur Tolerant Anode	Reduce op. and capital costs system simplification
Low Temperature Sulfur Sorbent	System simplification
Reforming Catalyst with Low Soot Formation Tendency	Reduced steam requirement, lower cost
Variable Activity Reforming Catalyst	Efficient cooling of stack (robust design)
High Rate Heat Exchangers	Rapid response (transportation application)
Direct Oxidation	Simple, low cost system with rapid response