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On-board Hydrogen Generation
for
PEM Fuel Cells
in
Automotive Applications

Tokyo, September 1999

Content

- Introduction
- Performance of individual components
  - Fuel reformer
  - CO clean-up
  - Afterburner
- Performance of integrated system
- Conclusions and future work

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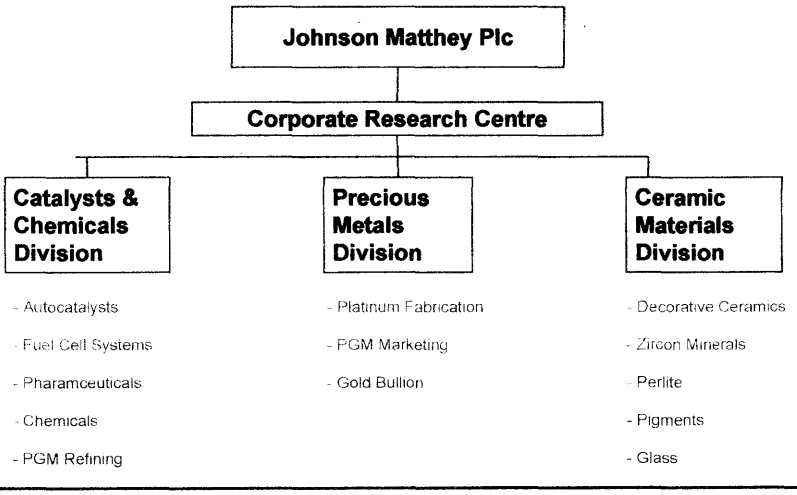
Group Overview

- British Company - Established in 1817 in London
- World leader in Advanced Materials Technology
- Employing 6,000 People in 38 Countries.
- Operating Profit of £147m on a Turnover of £3.4bn*.
- Sole PGM Marketing Agent for Amplats
  (formerly Rustenburg Platinum Mines Ltd)

* figures taken from 1999 annual report

Operational Structure



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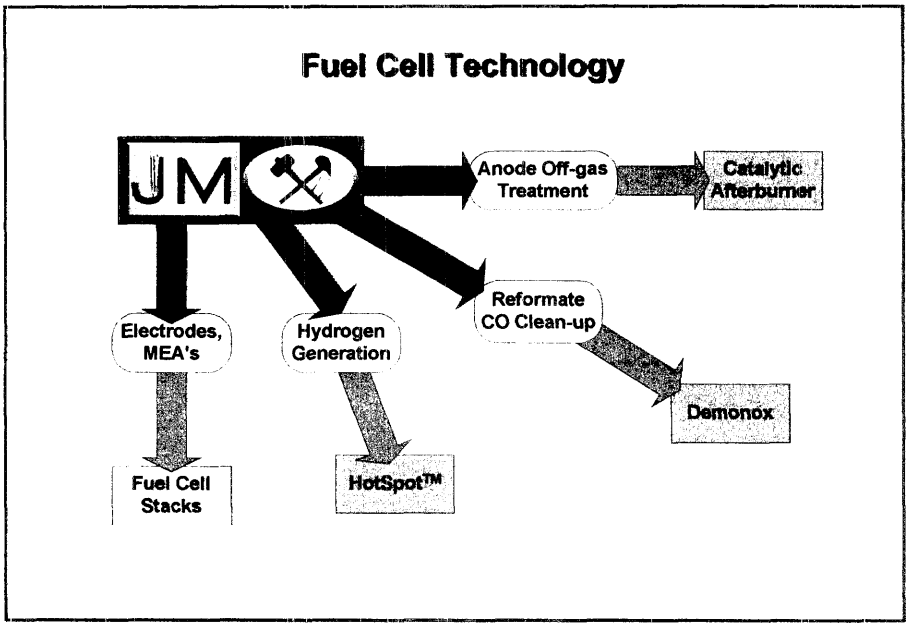

Impact of Transportation

Fact

USA in 1997*

Energy consumption

- 31% by transportation sector

Emissions due to on-road vehicles

- 57% CO, 30% NOx, and 27% VOC

*Source: EPA @ www.epa.gov/ttn/chief/trends97/browse.html

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Fuel Cells.....

.....have been identified as the most promising technology that can meet our future needs for transport applications, because they.....

- have high efficiency over a wide power range
- produce no harmful emissions (H_2 + 🖹 O_2 = H_2O)
- are quiet

Hydrogen

.....is one of the most abundant elements on Earth, and.....

- can be produced from (fossil/ renewable) fuels or water
- is a gas and has a very low energy density at ambient pressure and temperature
  (>3000 times less energy per volume than gasoline)

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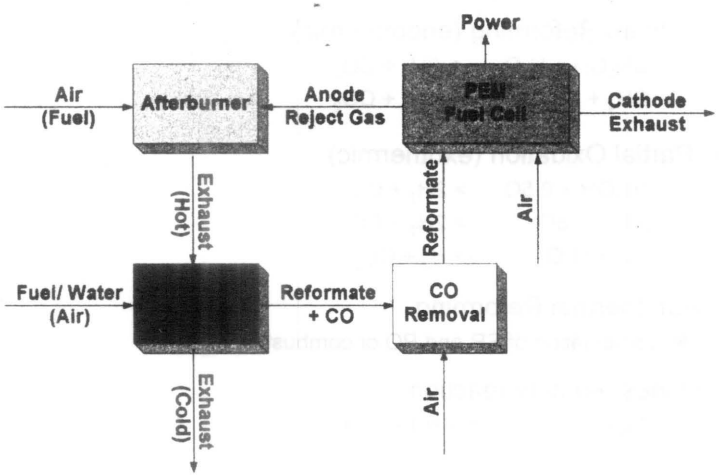
Hydrogen Storage Options

- **Physical**
  - Compress (200 - 600 bar)
    - bulky, difficult refueling, no infrastructure
  - Liquefy (20 K, 2 bar)
    - energy intensive, insulation, no infrastructure
  - Absorption by metal: -> metal hydride
    - heavy, no infrastructure
- **Chemical**
  - Hydrogen generation from Hydrocarbons or alcohols
    - more complex system
    - easy refueling

On-board H_2 generation



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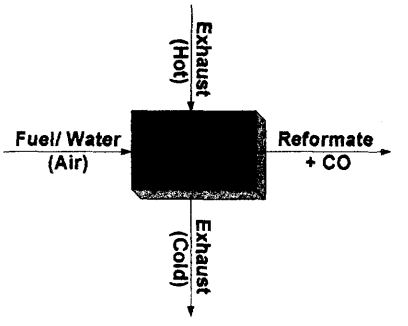
On-board H_2 generation: Reformer



Fuel Reformer

- Steam Reforming (endothermic)
  - $CH_3OH + H_2O$ -> $3H_2 + CO_2$
  - $CH_4 + 2H_2O$ -> $4H_2 + CO_2$
- Partial Oxidation (exothermic)
  - $CH_3OH + 0.5O_2$ -> $2H_2 + CO_2$
  - $CH_4 + 0.5O_2$ -> $2H_2 + CO$
  - $CO + H_2O$ -> $H_2 + CO_2$
- Autothermal Reforming
  - Combination of SR and PO or combustion
- Undesired side reaction
  - $CO_2 + H_2$ <-> $H_2O + CO$

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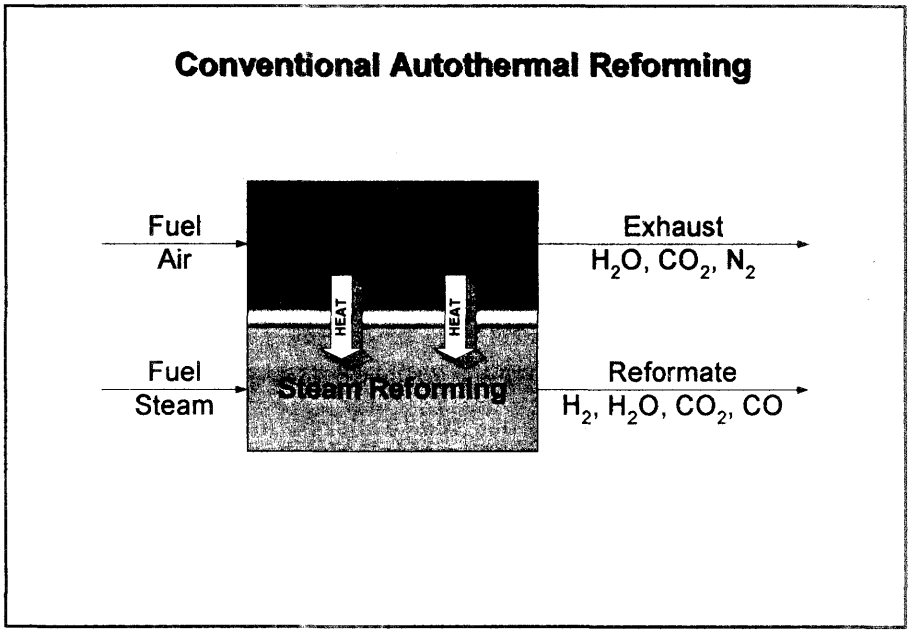

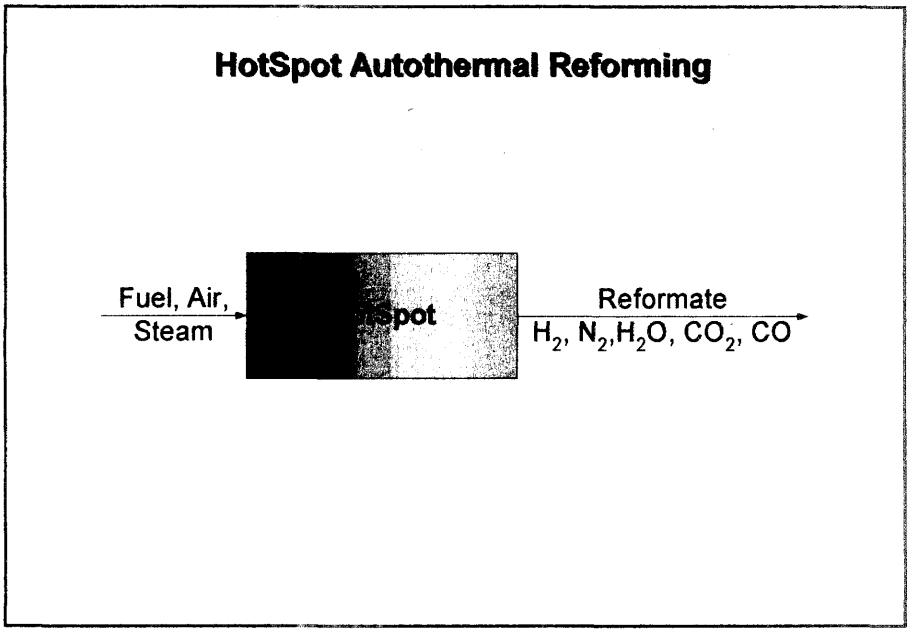

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HotSpot Autothermal Reforming

- Advantages
  - ü relatively small
  - ü fast start-up
  - ü good dynamic response
  - ü good efficiency
  - ü modular design, easy scale-up
- Can be applied to all types of HC's and alcohols
  - ü development most advanced for methanol and NG

CH_3OH HotSpot Reformer

Standard operation

- 6,000 litres of H_2 per hour
- 58% H_2 (dry product)
- 2.4..2.5 mol H_2 / mol CH_3OH
- Volume ~ 6 litre
- Mass ~ 9.5 kg
- Power ~ 6-7 kWe

Start-up with heated feed section

- start-up 20 s to 75%
- start-up 50 s to 100%

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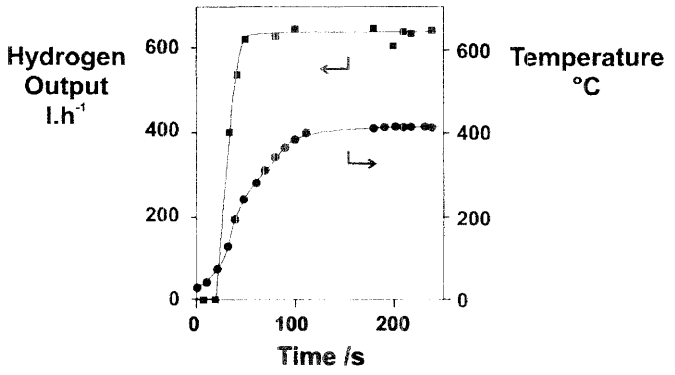
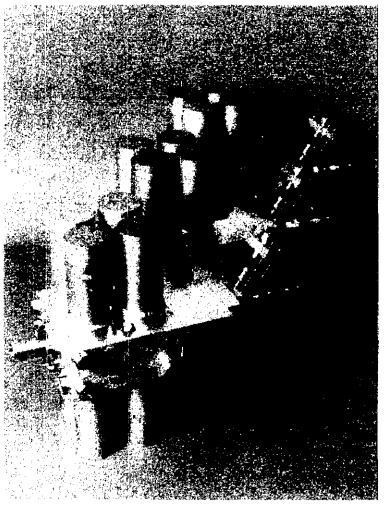
CH_3OH HotSpot Reformer: start-up



20 kW methanol HotSpot reformer



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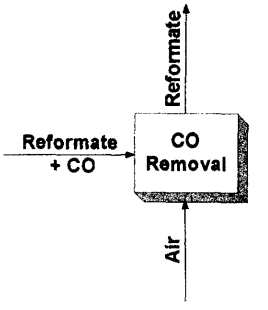
On-board H_2 generation: CO clean-up



CO clean-up

....Developed a multi-stage system mainly based on preferential oxidation....

- Tested with various reformate compositions
  - ü system can easily be adapted
  - ü methanol or water vapor has no detrimental effect
  - ü sensitive to sulfur components, but reversible
- Excellent Start-up and Transient Response
  - ü CO breakthrough negligible
  - ü 100% to 50% in seconds
  - ü CO spikes (2 - 4 times steady state content).....
    ..... can be attenuated effectively

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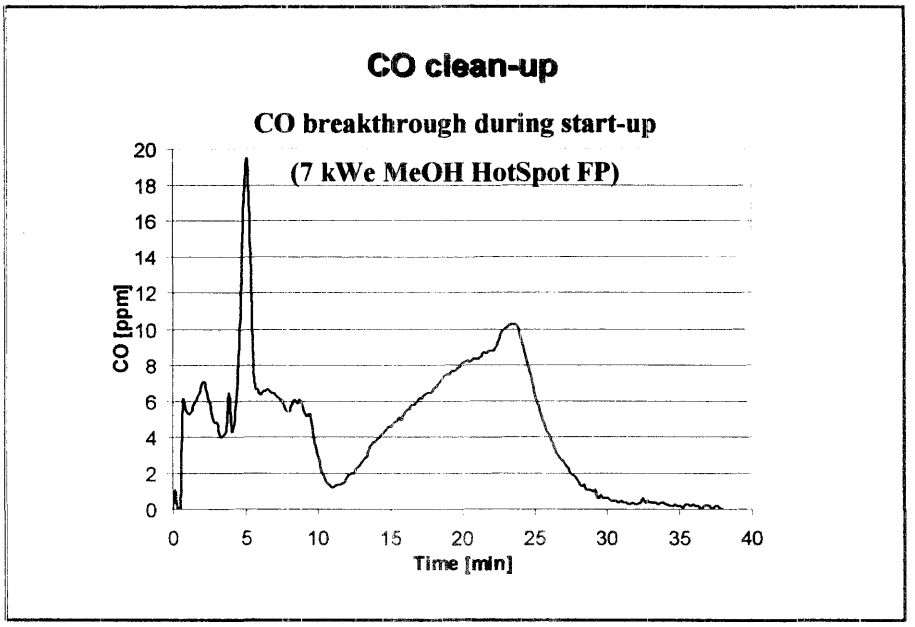

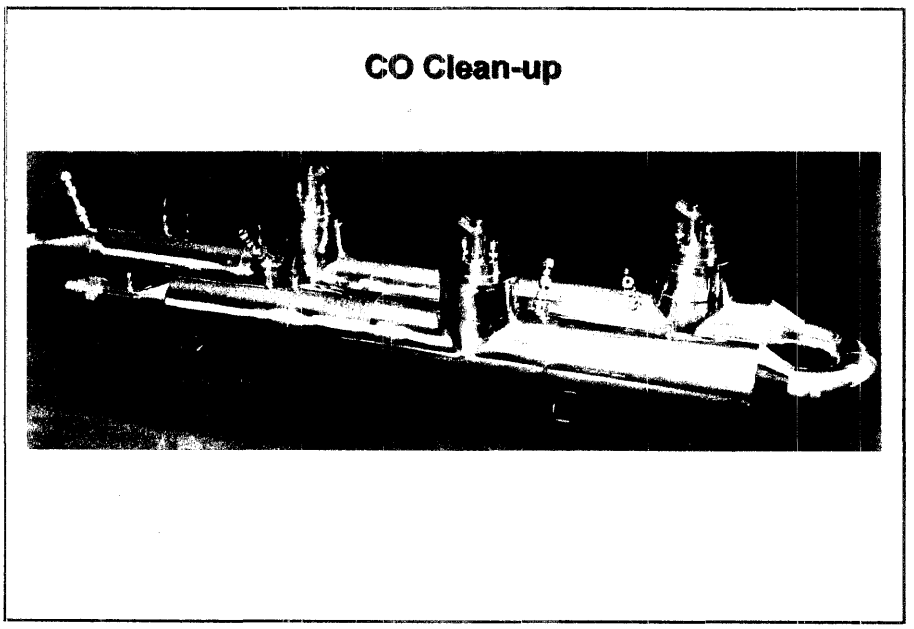

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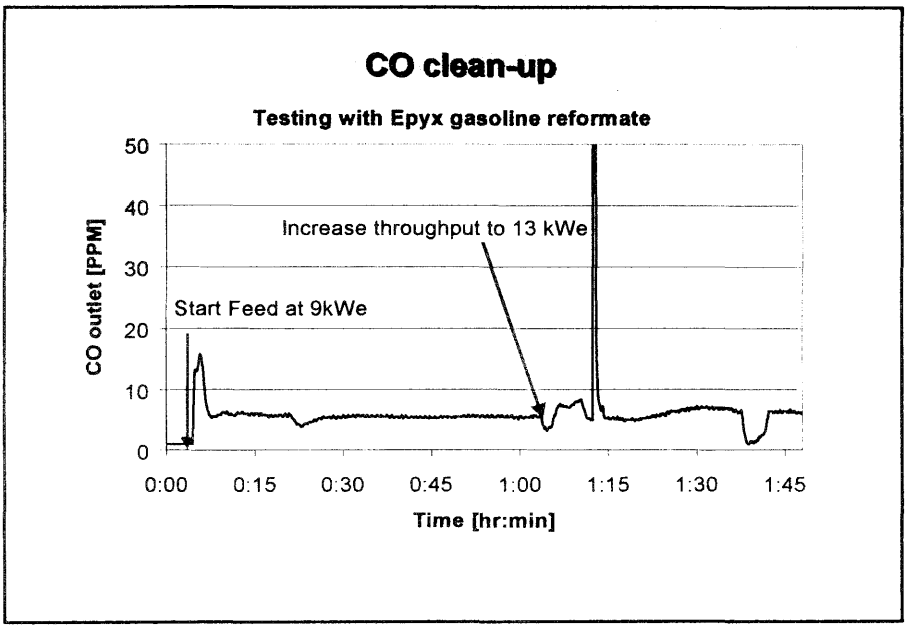

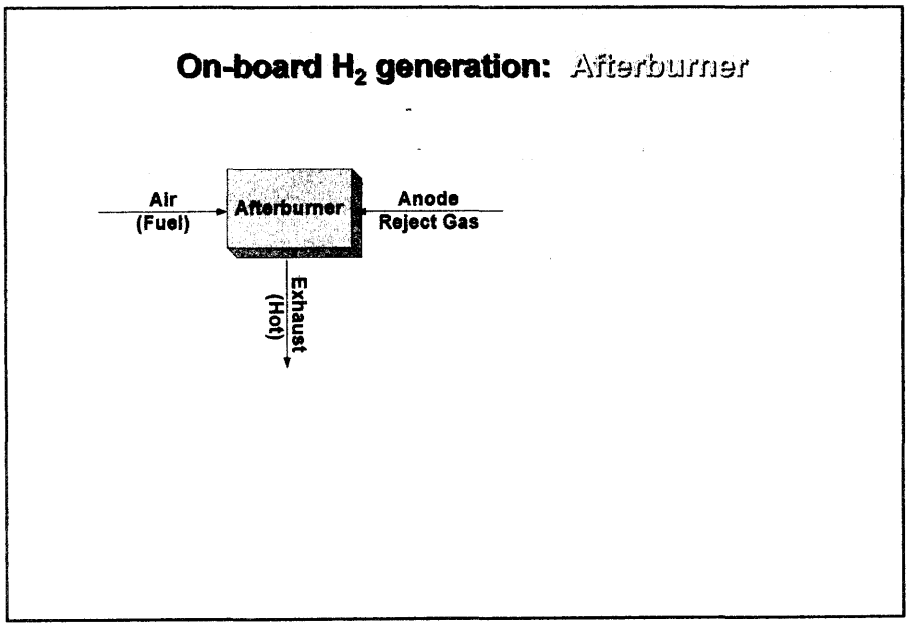

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Afterburner

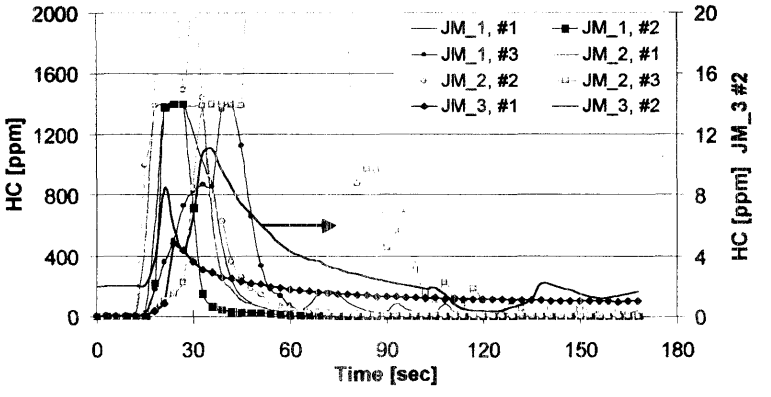
....Catalyst system developed for two functions.....

- During normal operation
  - ü Burn any combustible products in anode exhaust
  - ü Make harmful emissions negligible
  - ü Heat HotSpot feed section
- During start-up
  - ü Combust methanol to contribute to.....
    .....fast HotSpot start-up

Afterburner

MeOH breakthrough during start-up for different catalysts

Test performed with varying air/fuel ratios and total flowrates in micro-reactor



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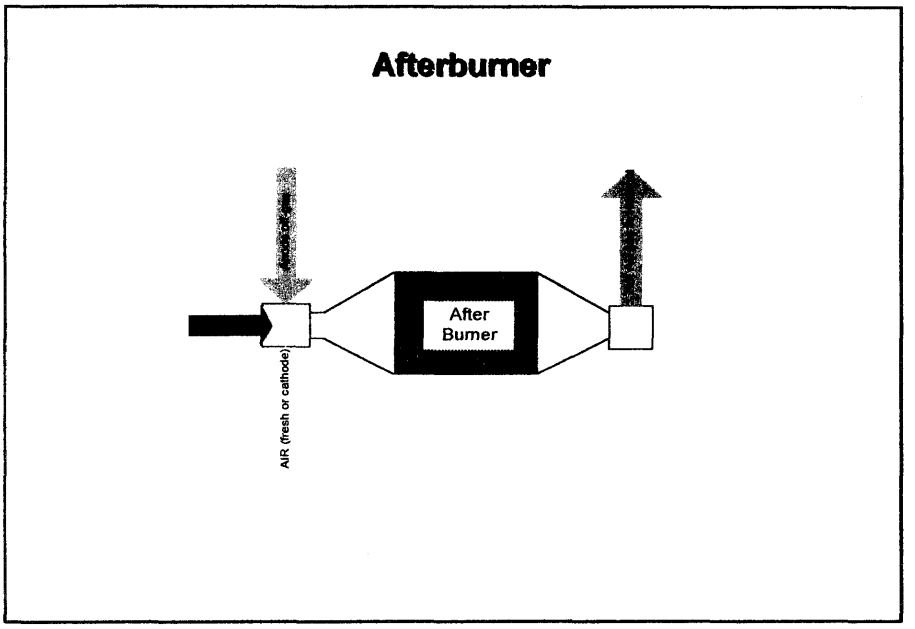

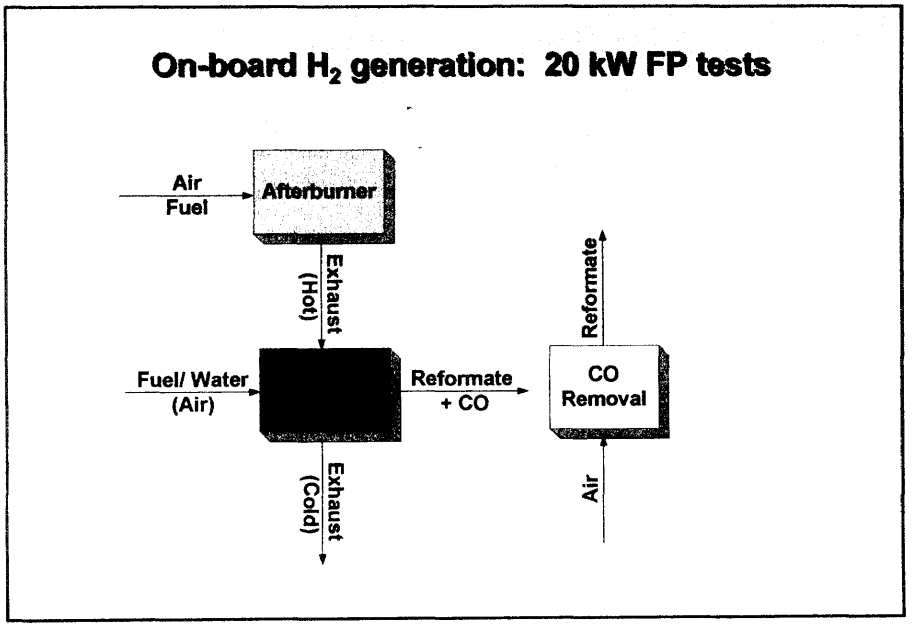

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20 kW FP start-up tests

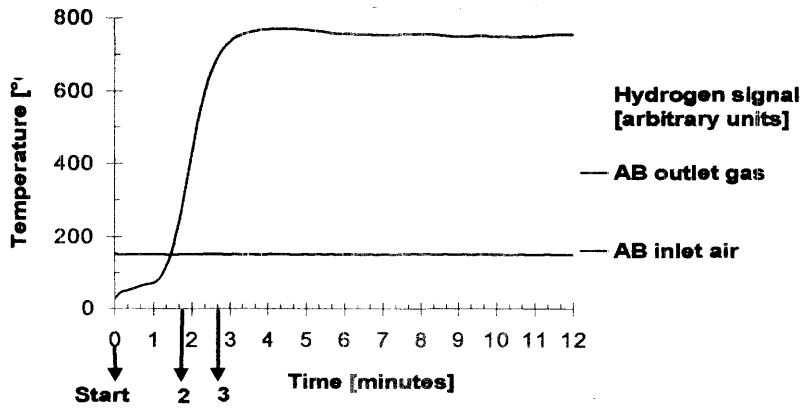
.....Performed at ~27% of maximum throughput.....

1 - start methanol and air flow to afterburner
- start methanol and air flow to HotSpot reformer under very lean combustion conditions
- start air flow to CO clean-up system

2 - start water feed to HotSpot reformer

3 - turn down air feed to HotSpot reformer to SS value

20 kW FP start-up tests



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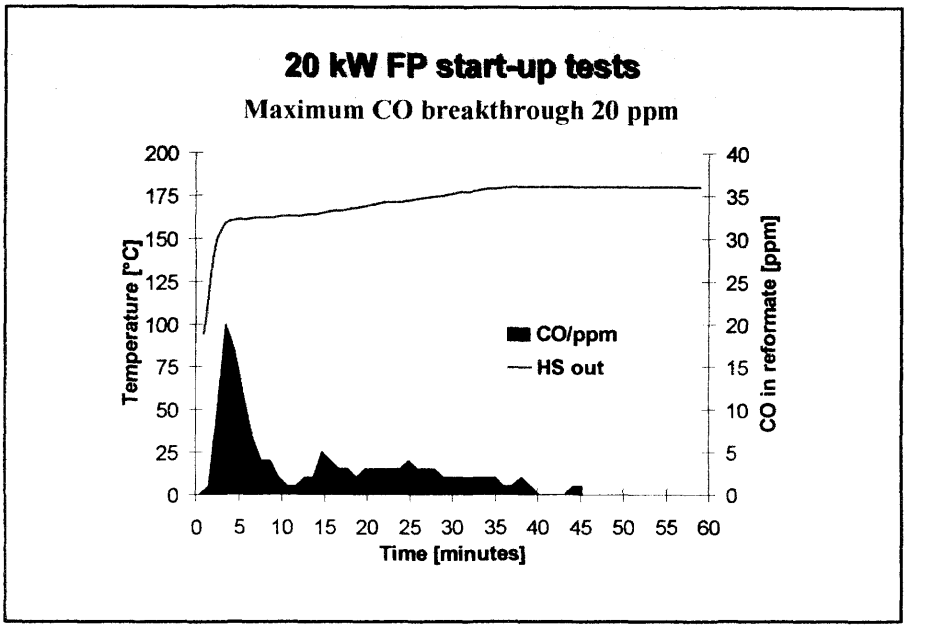

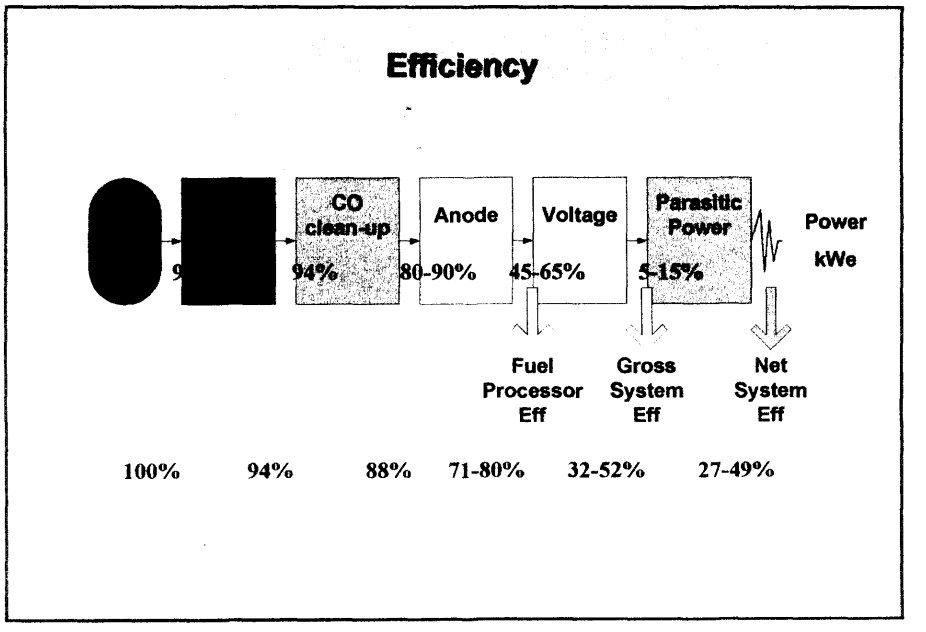

Conclusions

- Developed and demonstrated FP components suitable for automotive applications
  - ü HotSpot reformer
  - ü CO clean-up
  - ü catalytic afterburner
- Demonstrated the start-up of 20 kWe FP subsystem
  - ü reformate produced in 2 minutes
  - ü no CO breakthrough

Future Work

- Improve fuel processor system
  - ü system size and weight
  - ü engineering
    - è heat exchange, control, dynamic performance, pressure drop, fuel, water and air supply
  - ü reduce cost....reduce cost.....reduce cost....reduce cost
- Further develop HotSpot reforming
  - ü LPG, higher hydrocarbons