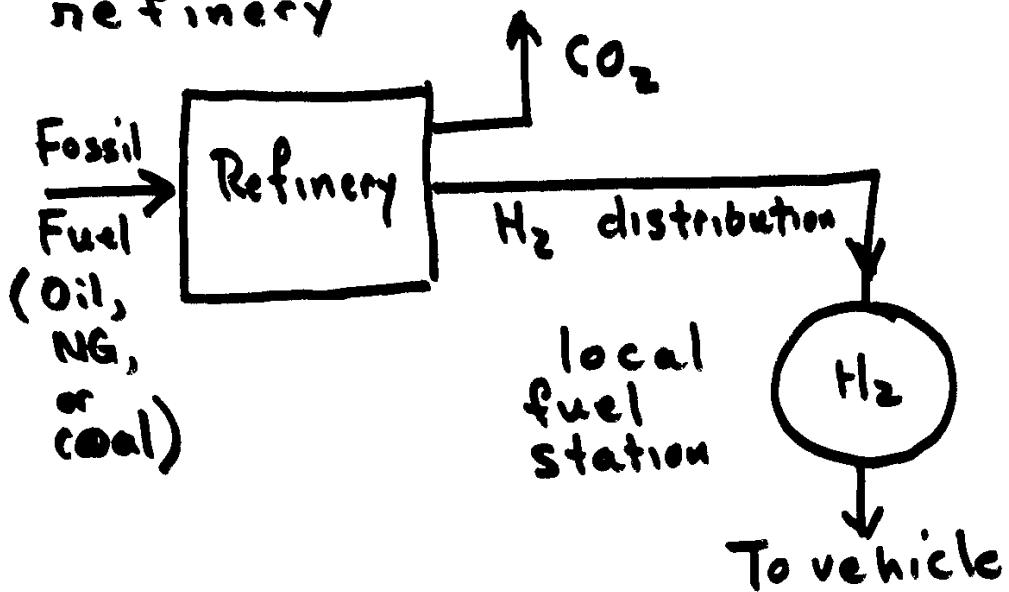


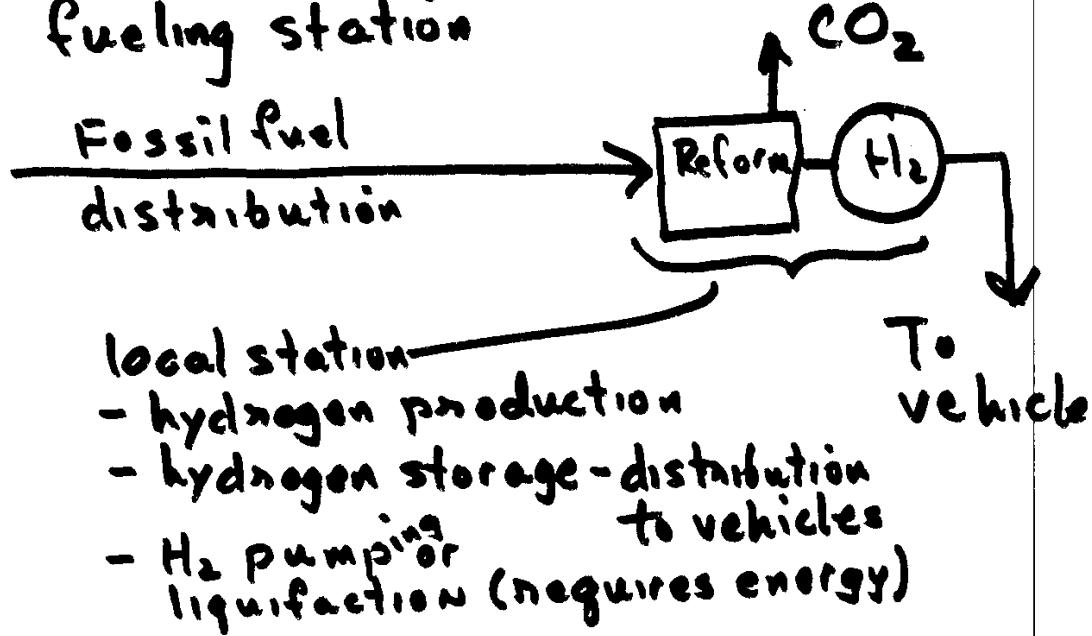
# Fuel Cell Electric Vehicle

## Hydrogen Carried On-board :

1. Hydrogen produced at refinery



2. Hydrogen produced at local fueling station



(2)

## Pros/Cons

1. Central refinery technology available

Infrastructure for central H<sub>2</sub> production and for nationwide distribution not available -- would be costly to develop

2. Most likely fuel candidate is NG, though oil should not be ruled out

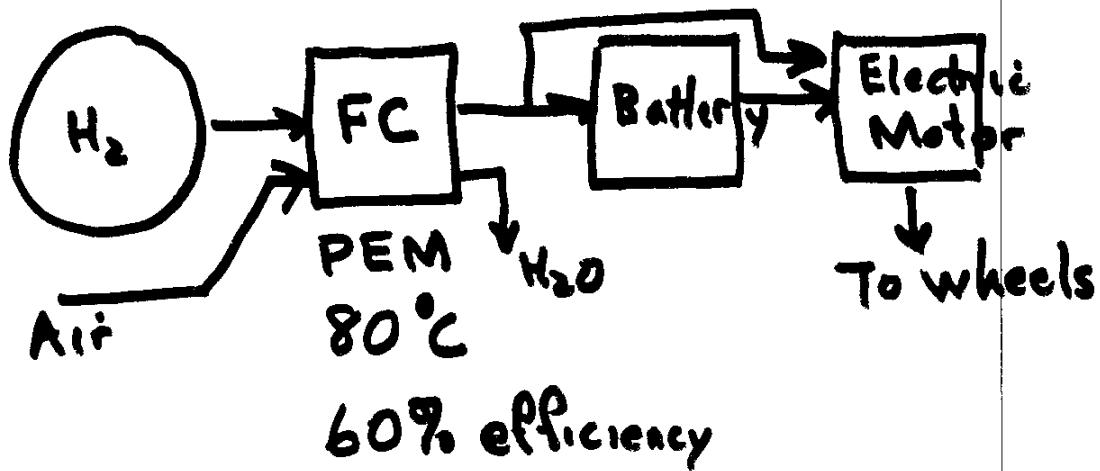
Infrastructure, i.e. local reforming and H<sub>2</sub> fueling stations, would need to be developed

What about producing H<sub>2</sub> by electrolysis of water?

- Inefficient at present
- Costly at present
- Is the source of the electricity fossil fuel, nuclear, or renewable?

(3)

## On board storage of H<sub>2</sub>



### Storage Options:

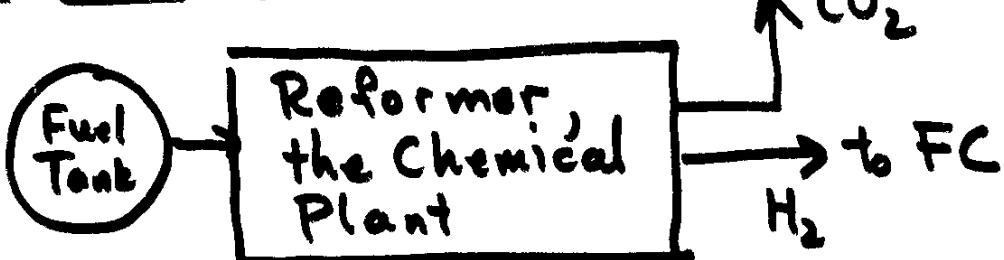
A. High-pressure tank (5000 psig)  
4 MJ/liter (vs 30+ MJ/liter gasoline)

B. Liquified H<sub>2</sub>  
8 MJ/liter  
Safety issue: H<sub>2</sub> boil-off  
Require cryogenic tank

C. Metal hydrides  
> 10 MJ/liter  
Store H in metal matrix  
Heavy (low MJ/kg)  
Expensive

(4)

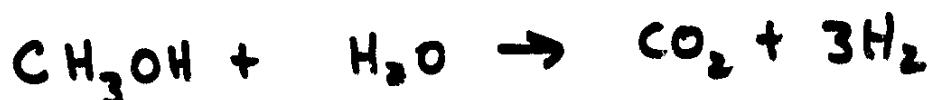
## On-board reforming of liquid HC fuel to H<sub>2</sub>



Type of reformer depends on type of liquid HC fuel

### A. Methanol

Steam reforming



Note:

This perfect reforming is not accomplished in practice -- have some CO in product gas

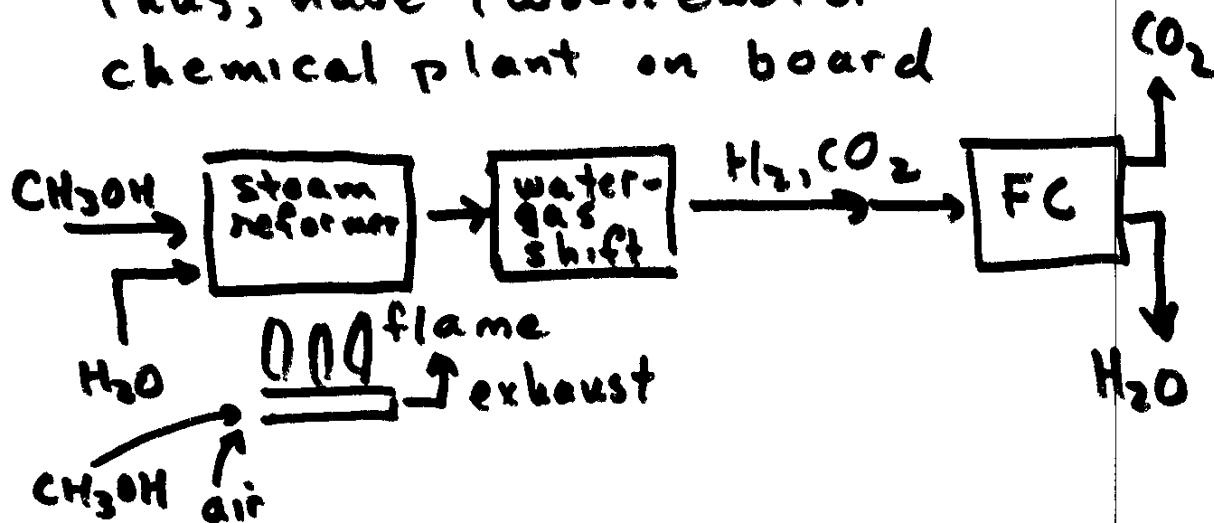
The PEM fuel cell is poisoned by CO -- thus must bring CO down to 10 to 100 ppm entering fuel cell

(5)

Can use water-gas shift reactor for this:



Thus, have two-reactor chemical plant on board



Note steam reforming is endothermic process -- requires source of heat

Note  $\text{CO}_2$  may not be separated from  $\text{H}_2$  -- i.e.  $\text{CO}_2$  may "go along for the ride" through the fuel cell

(6)

Steam reforming of  $\text{CH}_3\text{OH}$  is relatively easily accomplished (compared to the reforming of gasoline, diesel fuel, and ethanol to  $\text{H}_2$ ).

Thus, some of the demonstration fuel cell vehicles have been methanol powered.

However, the methanol reformer is relatively slow to warm up, and a fair amount of energy is required to manufacture methanol from NG (by steam reforming).

Nonetheless, substantial interest has been shown in the methanol fuel cell vehicle.

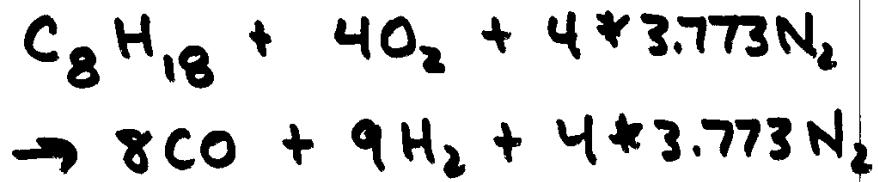
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### B. Fuel-grade gasoline \*

\* very low sulfur gasoline,  
minus octane-number  
enhancers (which aren't  
needed)

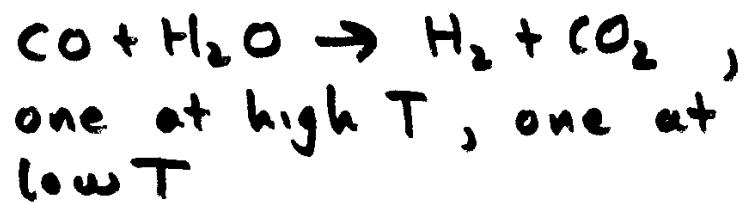
#### i. POX reactor

Partial oxidation reactor (POX)



Exothermic,  $T \approx 1000^\circ\text{C}$

Followed by two water-gas shift reactors,



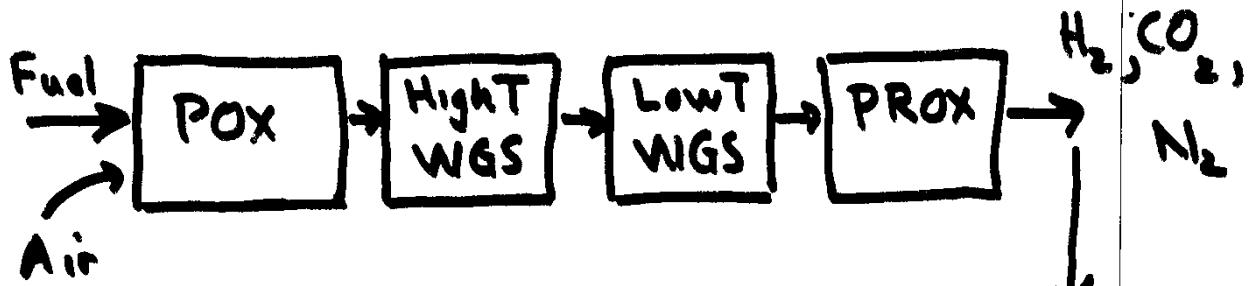
Followed by PROX reactor:

Preferential oxidation reactor, for destroying any remaining CO



(8)

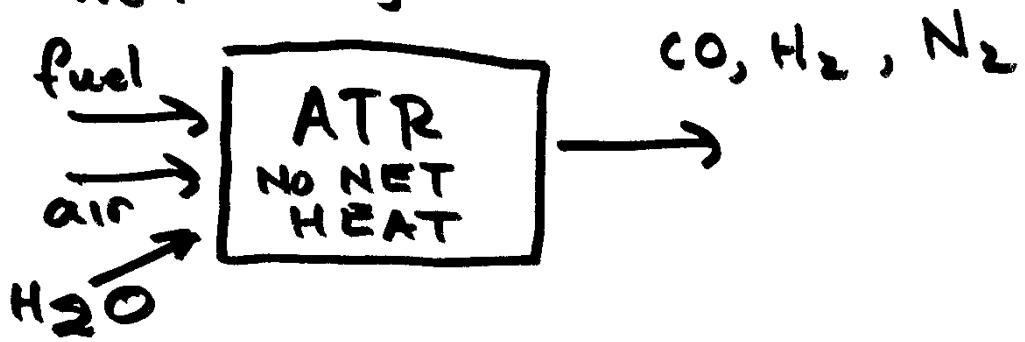
Complex!



Note need for significant temperature management and dissipation of heat from reformer

to F.C.  
at 80°C

Option: ATR = auto thermal reactor  
Combine partial oxidation with steam reforming -- balance exothermicity of partial oxidation with endothermicity of steam reforming



(a)

It is anticipated fuel cell vehicles will be available on a limited basis for purchase by 2004.

How will they be designed?

- Direct H<sub>2</sub> with tank of compressed H<sub>2</sub>?
- Methanol-fueled with methanol reformer?
- Gasoline-fueled with gasoline reformer?
- A different kind of fuel cell?
- None of the above?

Stay tuned -- it should be an interesting ride!

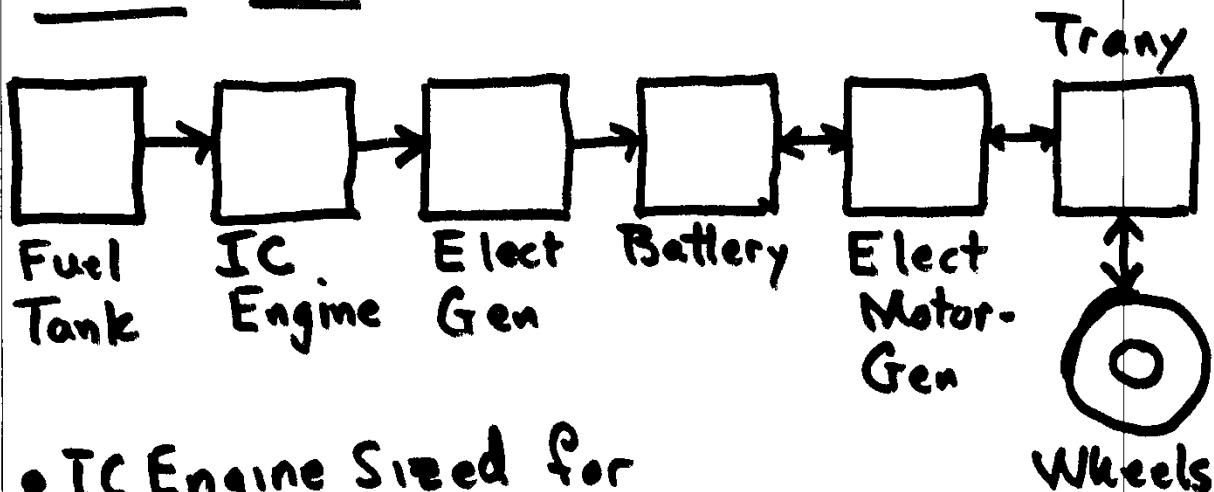
(10)

Billions of dollars are currently being spent on R D & D for transportation and stationary fuel cells.

- Very clean compared to combustion -- 70 to 90% less NO<sub>x</sub> (NO<sub>x</sub> from fuel reforming or refining)
- Twice as efficient for transportation than gasoline engine --  $\leq 50\%$  the CO<sub>2</sub> emission
- Co-gen for the homeowner -- NG fired FC
- Combined FC-GT cycle of  $\approx 70\%$  efficiency.  
Solid Oxide Fuel Cell ( $800 - 1000^\circ\text{C}$ ).

# Hybrid Electric Vehicle (HEV)

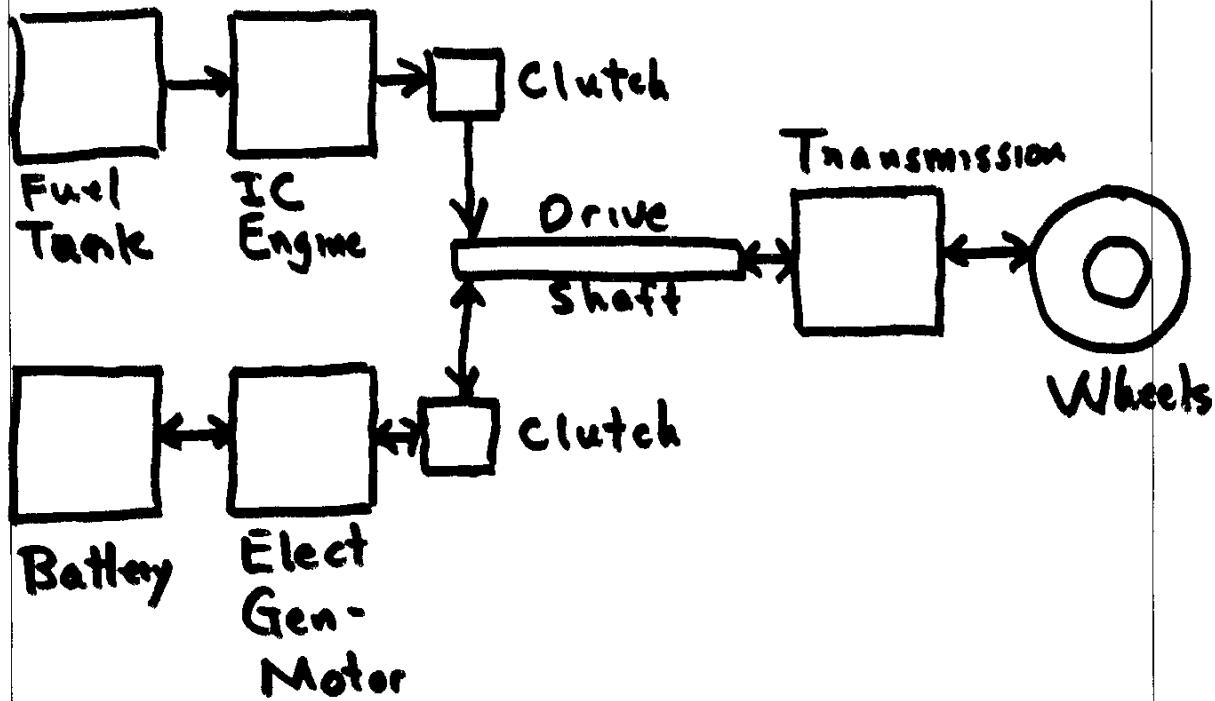
## Series Type



- IC Engine Sized for Average Power Demand -- rather than peak power. Thus smaller IC Engine
- IC Engine run at optimum conditions for best efficiency and lowest emissions
- IC Engine (through electrical generator) and Regeneration (braking and deceleration) charge the battery
- Battery "drives" electric motor, which drives wheels through transmission.

(13)

## Parallel Type



- IC Engine drives wheels and charges the battery
- Battery through electrical motor drives wheels which
- Regenerative braking and deceleration charge the battery

Modes of running parallel hybrid electric vehicle:

Power to wheels is:

1. Battery power for starting
2. Battery power for low vehicle speeds and power needs -- outside of optimum regime of IC engine
3. IC engine and battery power for cruising
4. High power needs (acceleration, hill climbing): IC engine assisted by battery power
5. Deceleration and braking -- regenerative energy recovery -- charge the battery

## Advanced IC Engine:

- 1 to 1.5 liter (versus  $\geq 2$  liters for most vehicles today)
- Low friction loss ( $\leq 4000$  RPM)
- Low pumping loss (special high expansion ratio cycle)
- Variable valve timing
- Very low emissions

High efficiency, low emission  
IC engine