PLASMA-ASSISTED COMBUSTION SYNTHESIS OF HYDROGEN

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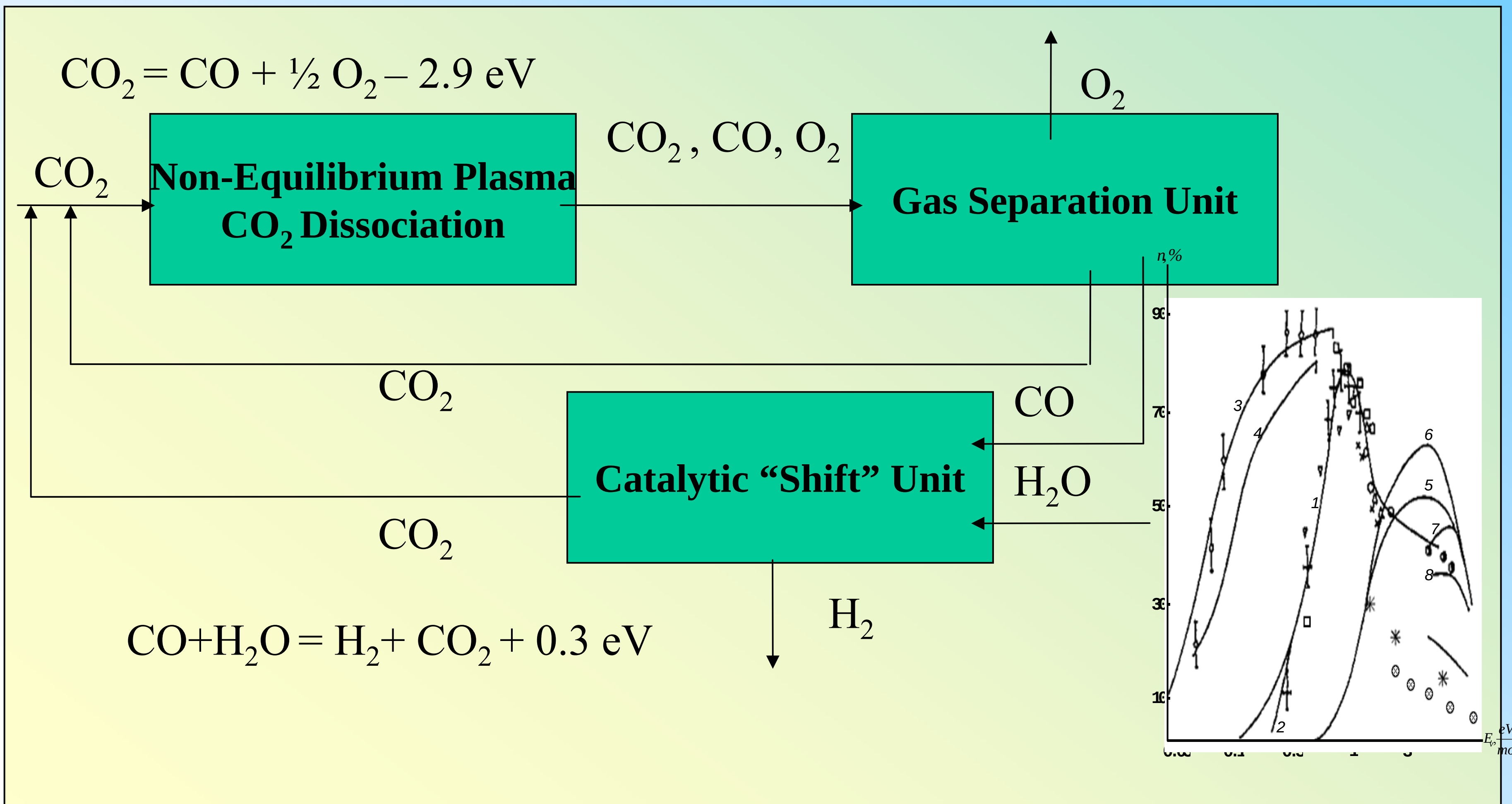
Hydrogen Production from Hydrocarbons, H2O and H2S, Stimulated by Non-Thermal Atmospheric Pressure Plasma

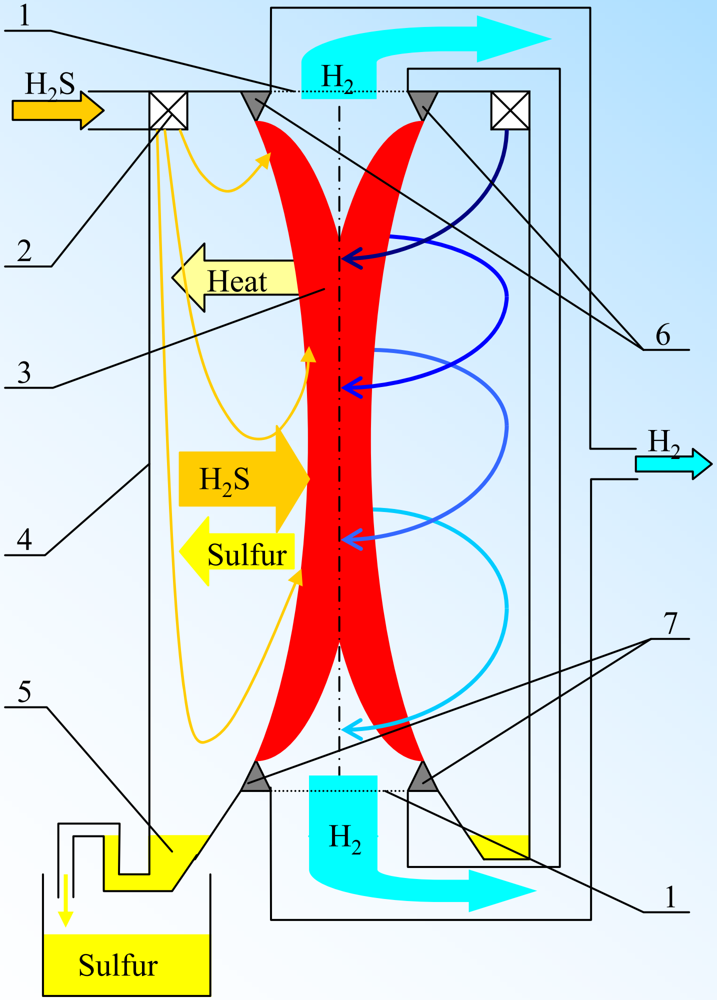
- Plasma-Chemical Hydrogen Production from Water
- Plasma-Chemical Hydrogen Production from H2S
- Plasma-Assisted Partial Oxidation of Methane
- Hydrogen Production in Tornado/Gliding Arc
- Experiments vs Modeling

Non-Equilibrium Plasma-Chemical Hydrogen Production from Water

H2 Production Cycle Based on CO2 Dissociation in Plasma

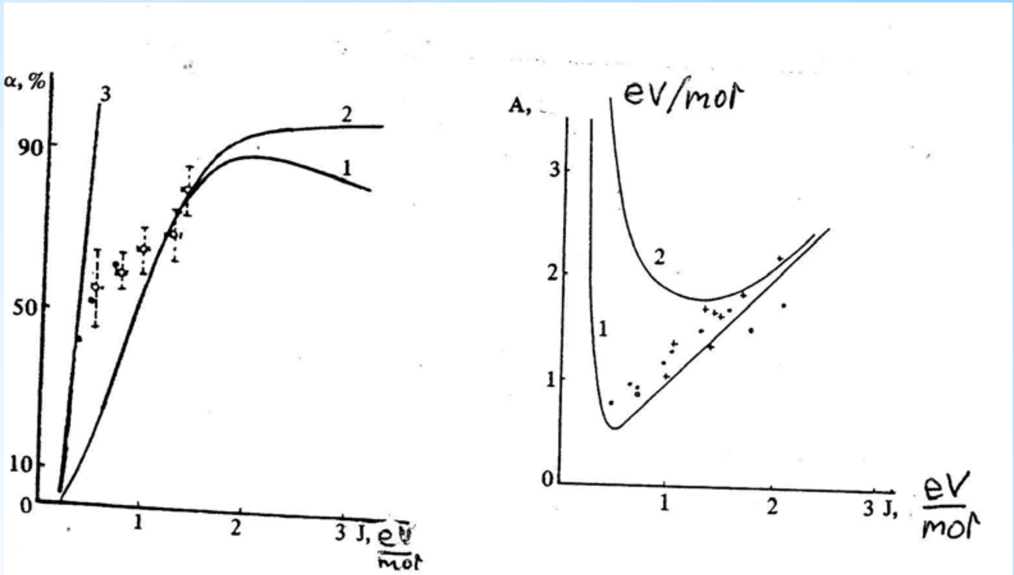


H2S Dissociation in Gliding Arc Tornado



Process Characteristics:

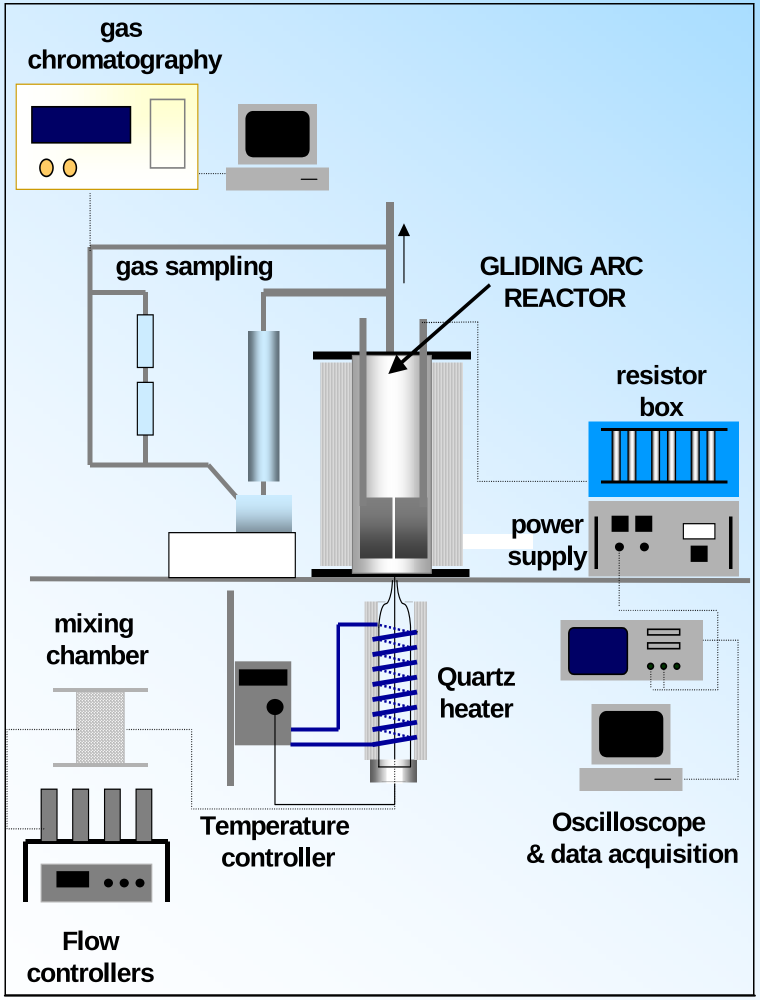
- Gas Temperature 200-400C
- Electron Temperature 15,000K
- H2S Conversion Degree: 95%
- Products: Hydrogen, Sulfur
- Energy Cost: 0.8 kWh/m3 H2



PLASMA-ASSISTED COMBUSTION SYNTHESIS OF HYDROGEN

ChevronTexaco

Plasma Catalytic H2 Production from Natural Gas



Plasma PO optimal parameters:

$$CH_4 + 0.5O_2 = CO + 2\,H_2$$

optimal equivalence ratio = 3.3,

[O2]/ [CH4]=0.6

Preheating temperature = Internal, 750K

Conversion = 92%

Electric energy cost :

- experimental = 0.06 kWh/m^3
- modeling EQ = 0.11 kWh/m^3
- modeling NE = 0.07 kWh/m^3

Output Syn-Gas energy = 3.00 kWh/m^3

power for 100,000 barrel/day of Liquid Fuel:

- experimental = 4.5 MW
- modeling EQ = 8.2 MW
- modeling NE= 5.2 MW

PLASMA-ASSISTED COMBUSTION SYNTHESIS OF HYDROGEN

Plasma Catalysis Vs. Thermo-Catalytic Partial Oxidation

$$CH_4 + 1/2\ (O_2 + 3.76\ N_2) \xrightarrow[\text{Temperature}]{\text{Catalysis}} CO + 2\ H_2 + 1.88\ N_2 + 36\ \text{kJ/mol}$$

Thermo-Catalytic Conversion:

- High Temperature Requirements (>1100K)
- Large Specific Size of Reactor
- Special Materials Requirements and Reactor Design
- Sulfur from Natural Gas Causes Catalyst Poisoning
- Low Conversion at Moderate Equivalence Ratios (3.0-3.5)

Plasma-Catalysis:

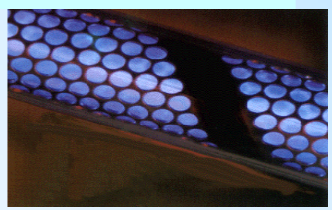
- Low Temperature Operation (~750K)
- Large Specific Productivity
- Lower Temperature Requirements
- No Sensitivity to sulfur or other impurities
- Possibility to Operate at High Equivalence (3.5-4.5)

Gliding Arc as Transitional Non-Equilibrium Plasma:

THERMAL PLASMA

- Very High Plasma power and density.
- High Gas temperature.
- No selective chemical process can be achieved.

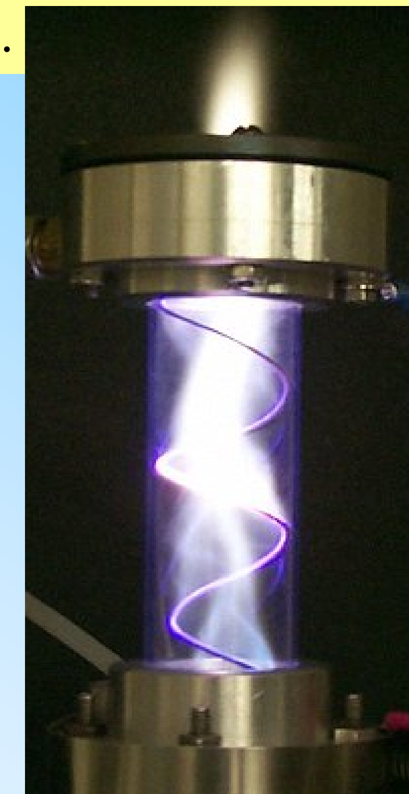
NON-THERMAL PLASMA



- Low gas temperature and very high electron temperature.
- Low Power Density
- Chemical Selectivity can be achieved.

MAJOR CHALLENGES :

- Power Density & Productivity.
- Selectivity.

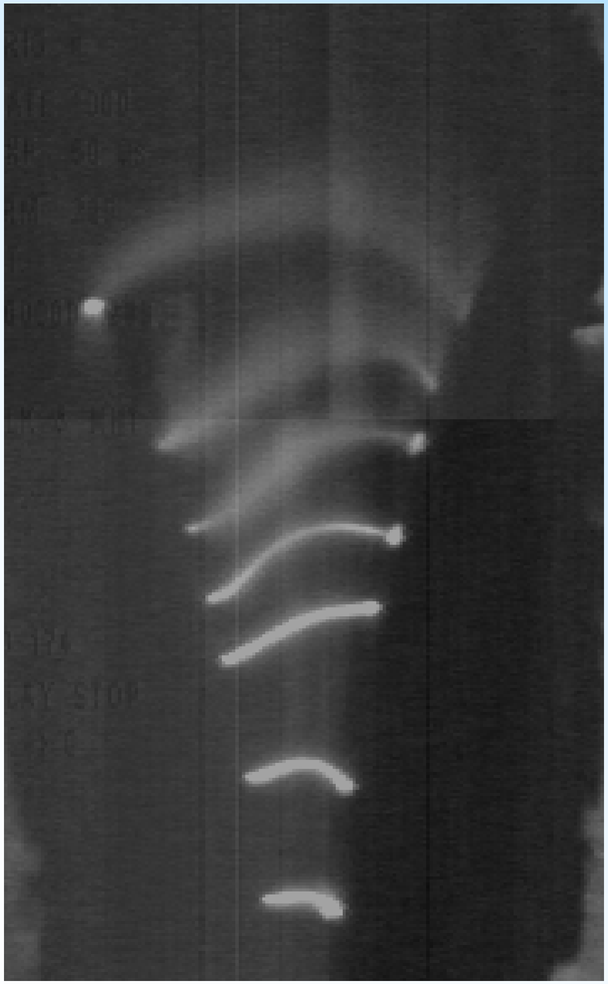


"Gliding Arc in Tornado"

ChevronTexaco

“GLIDING ARC in Flat Geometry”

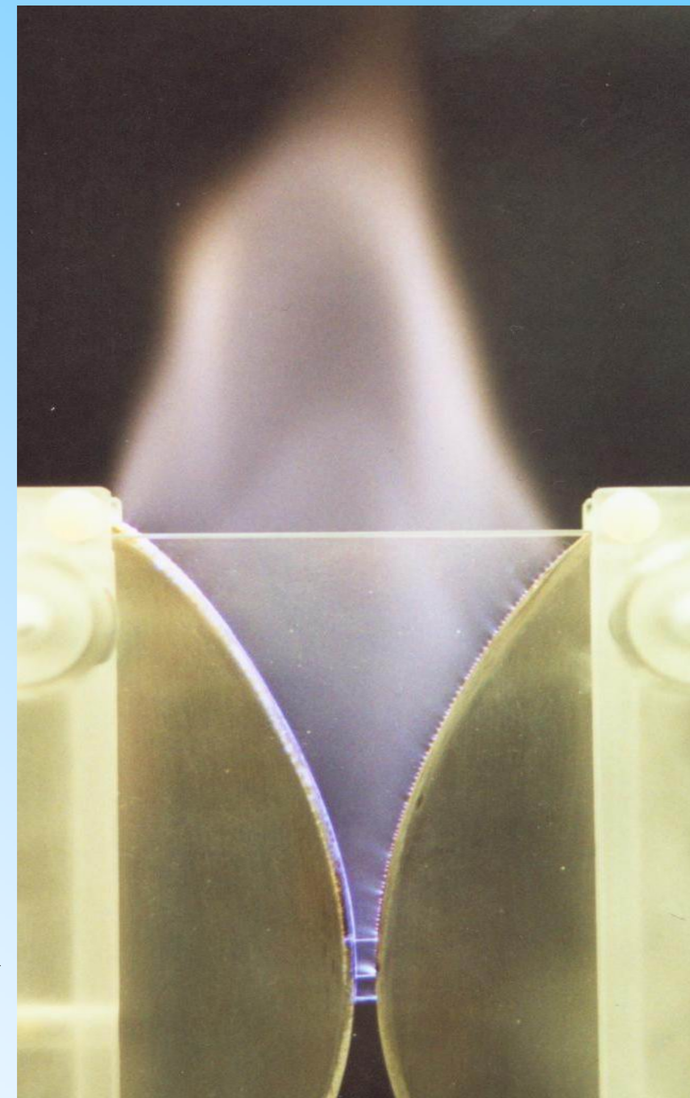
Fast Equilibrium to Non-Equilibrium Transition



Extinction

Elongation

←Initial Breakdown→



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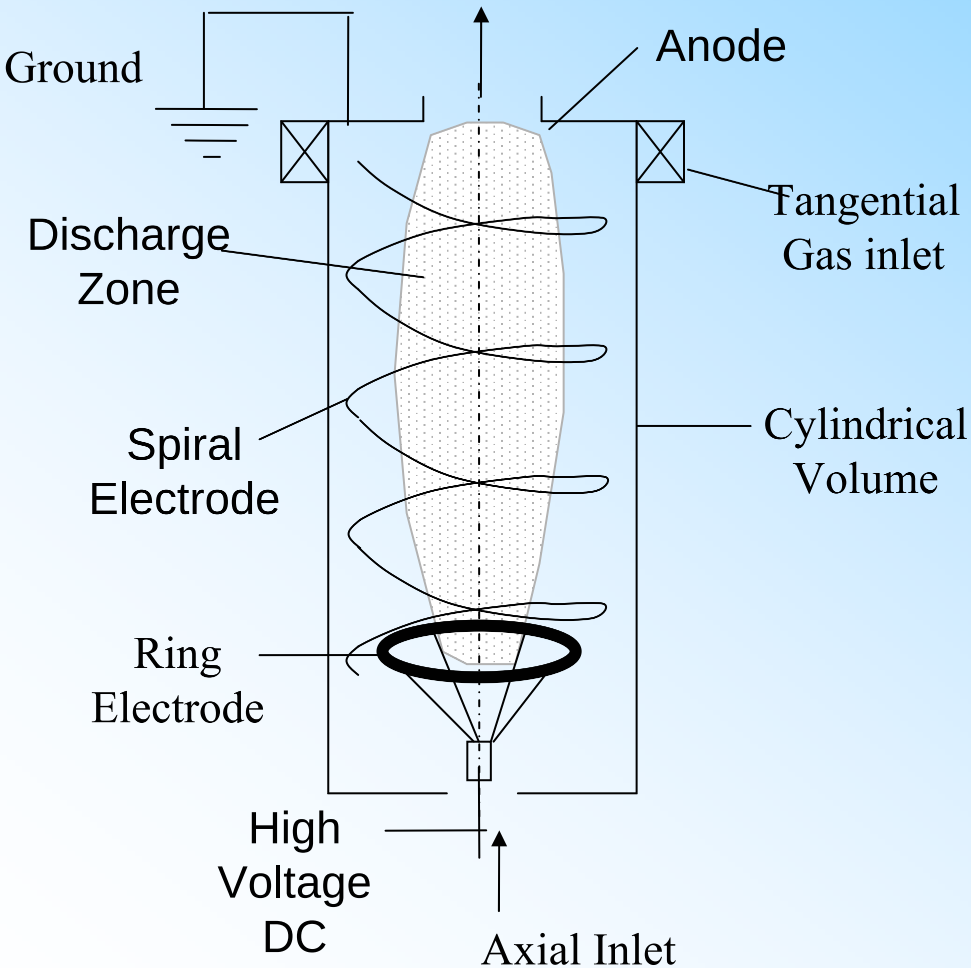
"THE GLIDING ARC IN TORNADO"

Gliding Arc in Tornado Flow



Schematic Diagram for GAT reactor.

•Gliding Arc in Tornado works in a Reverse Vortex Flow setup.

•A circular and spiral electrode is placed in the plane of the flow act as diverging High Voltage DC Electrodes.

•The flow conditions and the characteristics of the power supply determine the shape of the spiral electrode.

Gliding Arc "Tornado"

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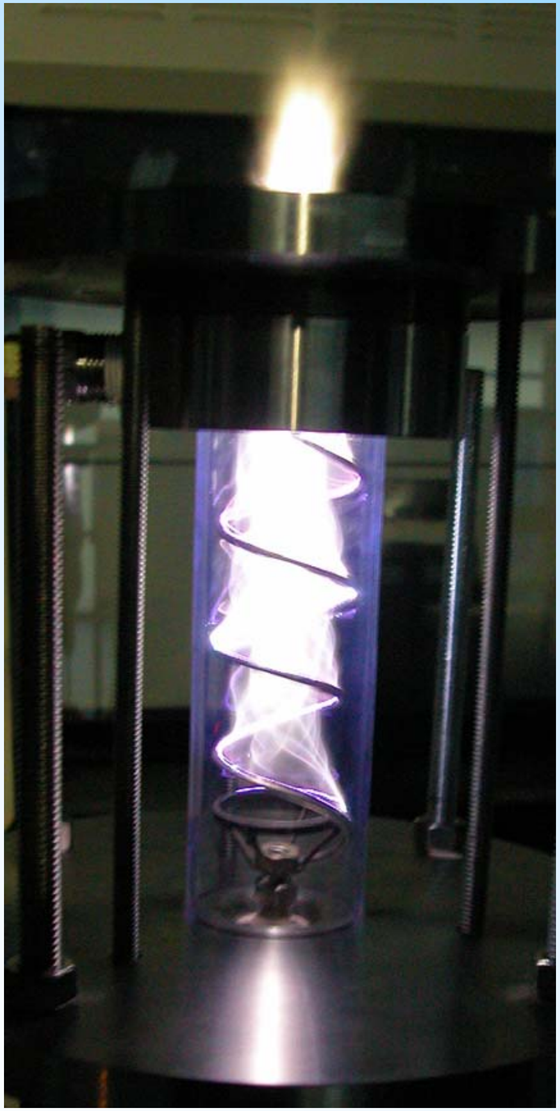
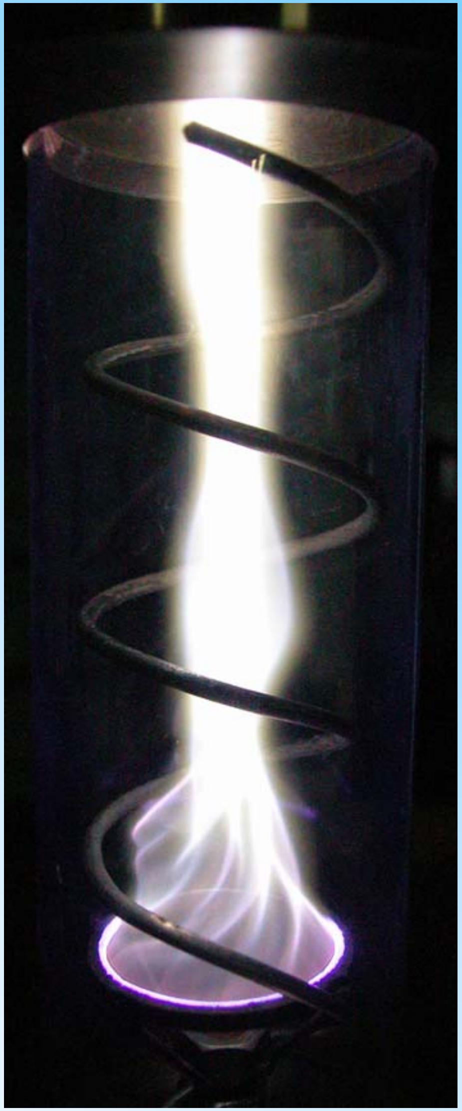
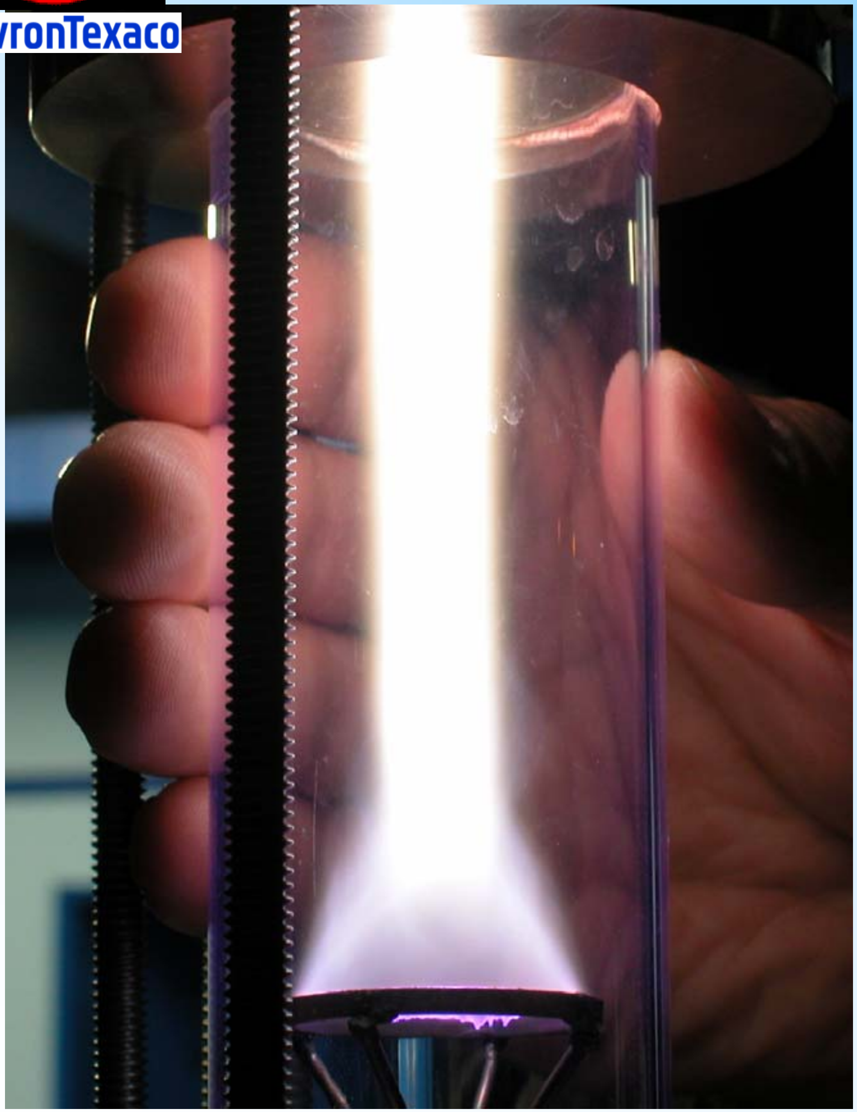
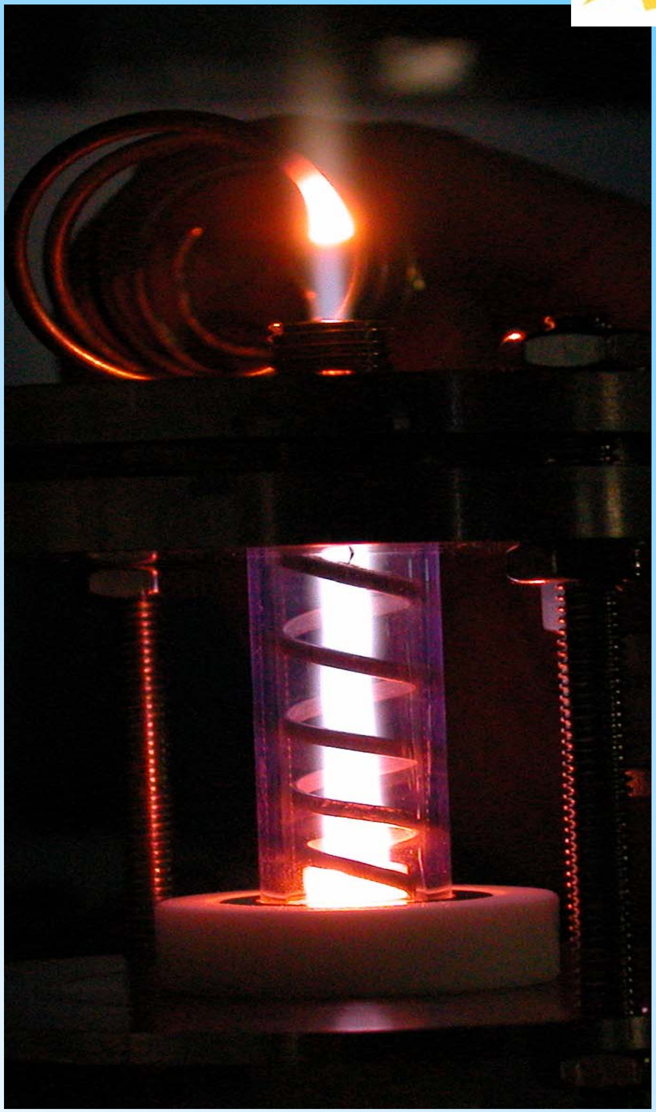


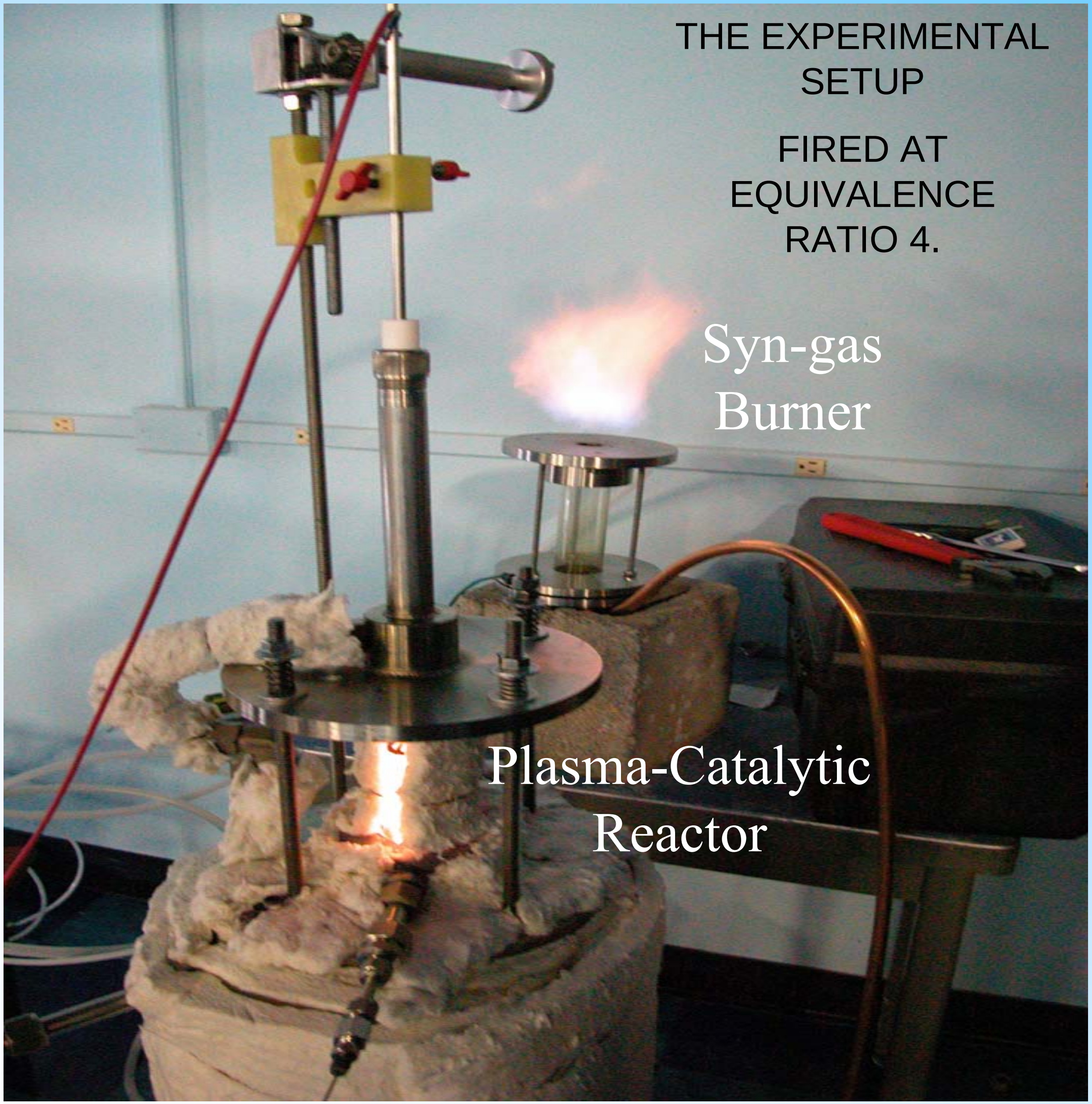


Gliding Arc "Tornado"

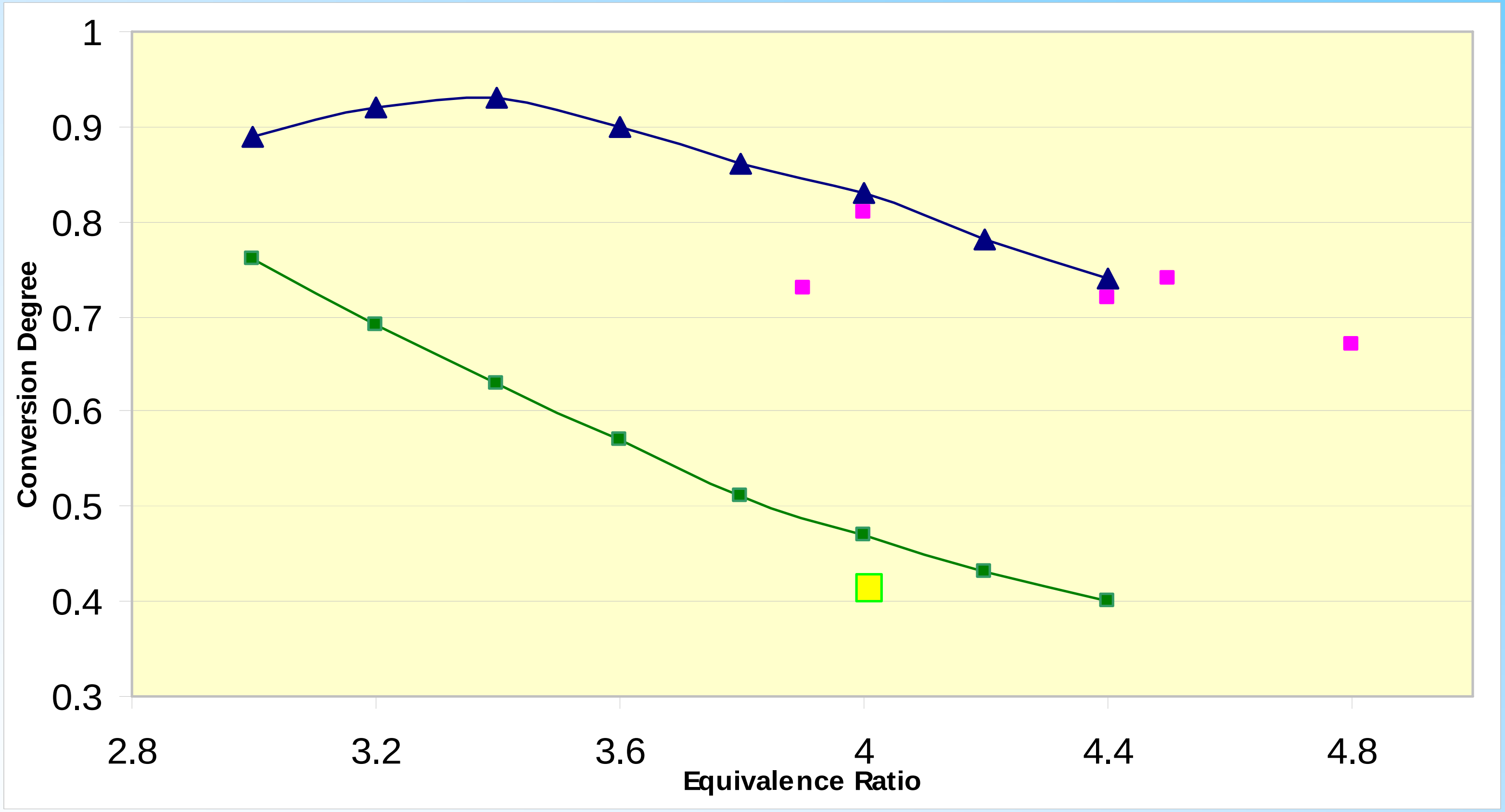
"It Can Melt a Metal Rod But You Can Touch It"

Plasma Catalytic Methane Partial Oxidation



Simulation Vs Experiments

The conversion degree: $\alpha = ([H_2] + [CO]) / 3[CH_4]$



▲ Modeling results With plasma

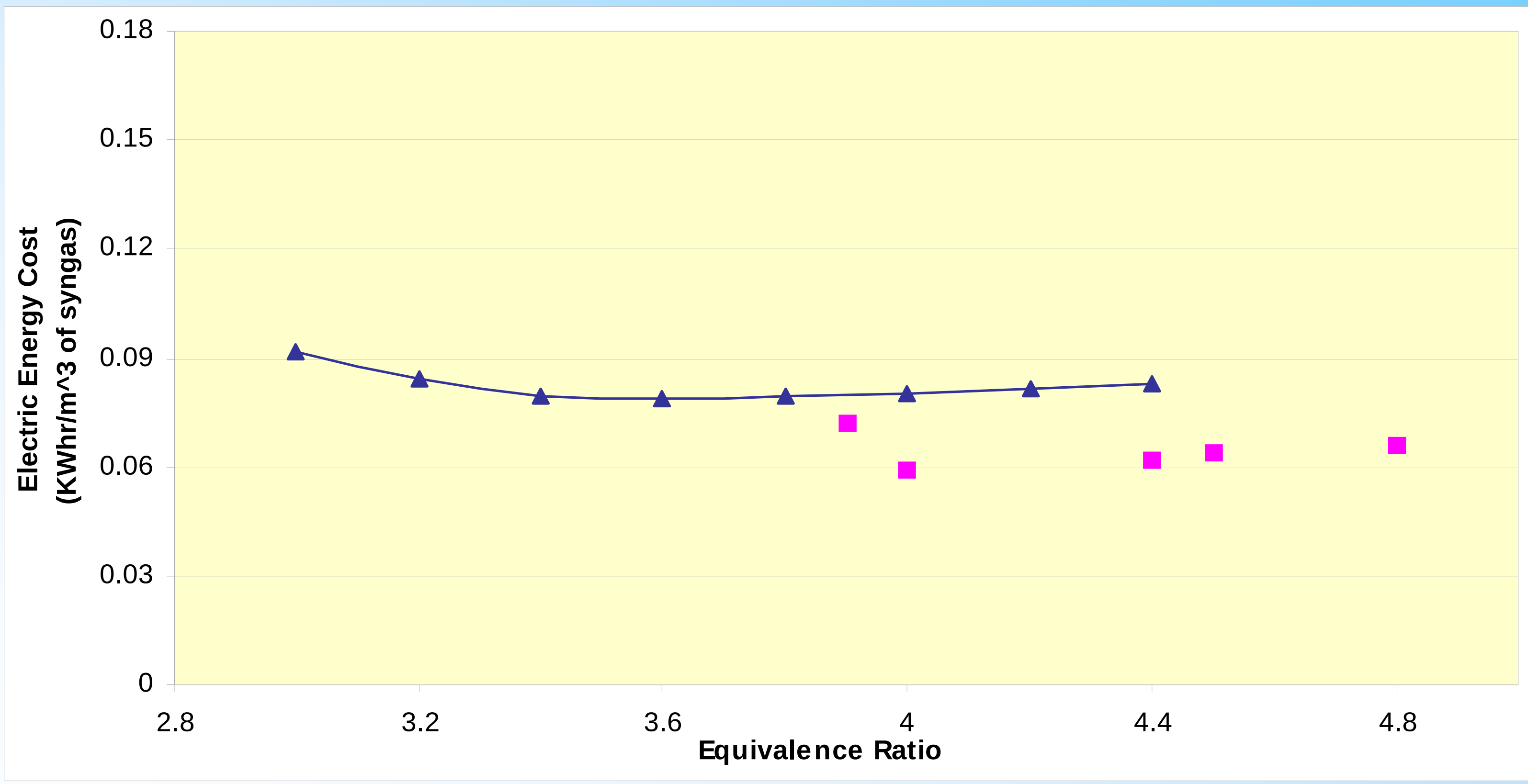
■ Modeling results without plasma

■ Experimental results with plasma

□ Experimental results without plasma

Simulation Vs Experiments

Electric Energy Cost = W_{el}(KW-hr)/ meter cube of Syn-Gas (Output Syn-Gas Energy = 3.00 kWh/m^3)

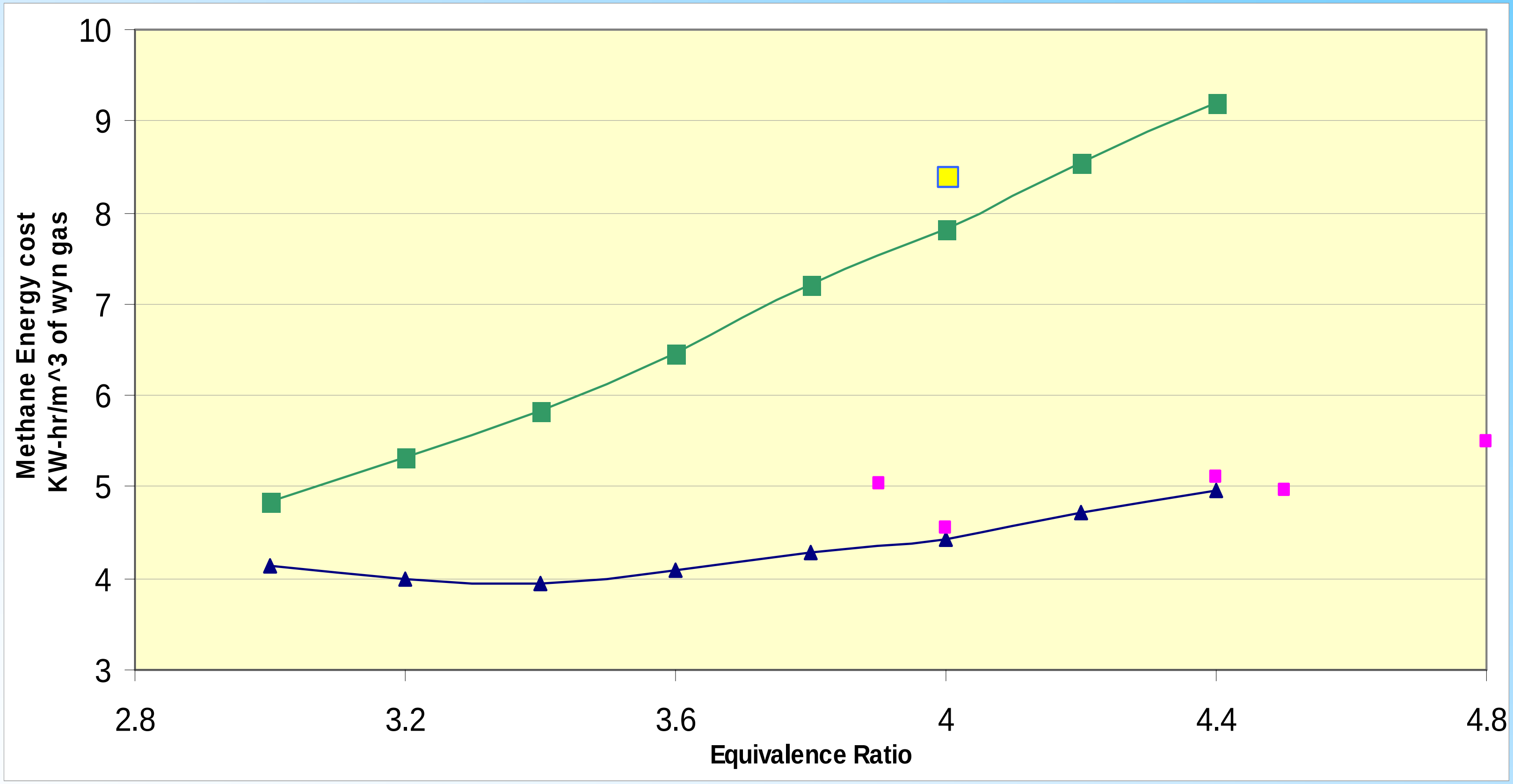


▲ Modeling results

■ Experimental results

Simulation Vs Experiments

Methane Energy Cost = [CH4] (KW-hr) per meter-cube of Syn-Gas



▲ Modeling results with Plasma

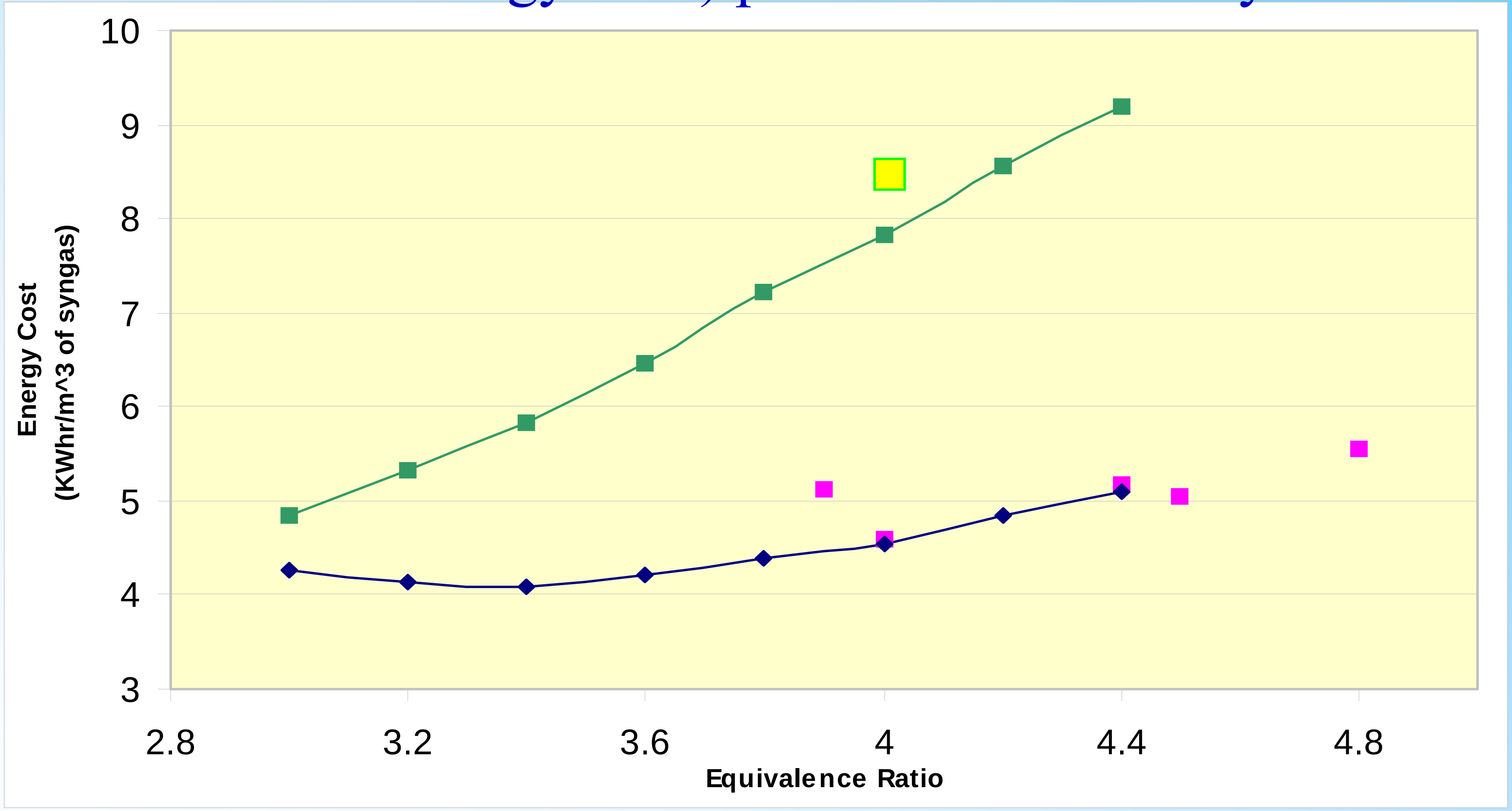
■ Modeling results without plasma

■ Experimental results with plasma

■ Experimental results without plasma

Simulation Vs Experiments

Total Energy Cost = (Electric Energy Cost + Methane Energy Cost) per meter Cube of Syn-Gas



▲ Modeling results With plasma

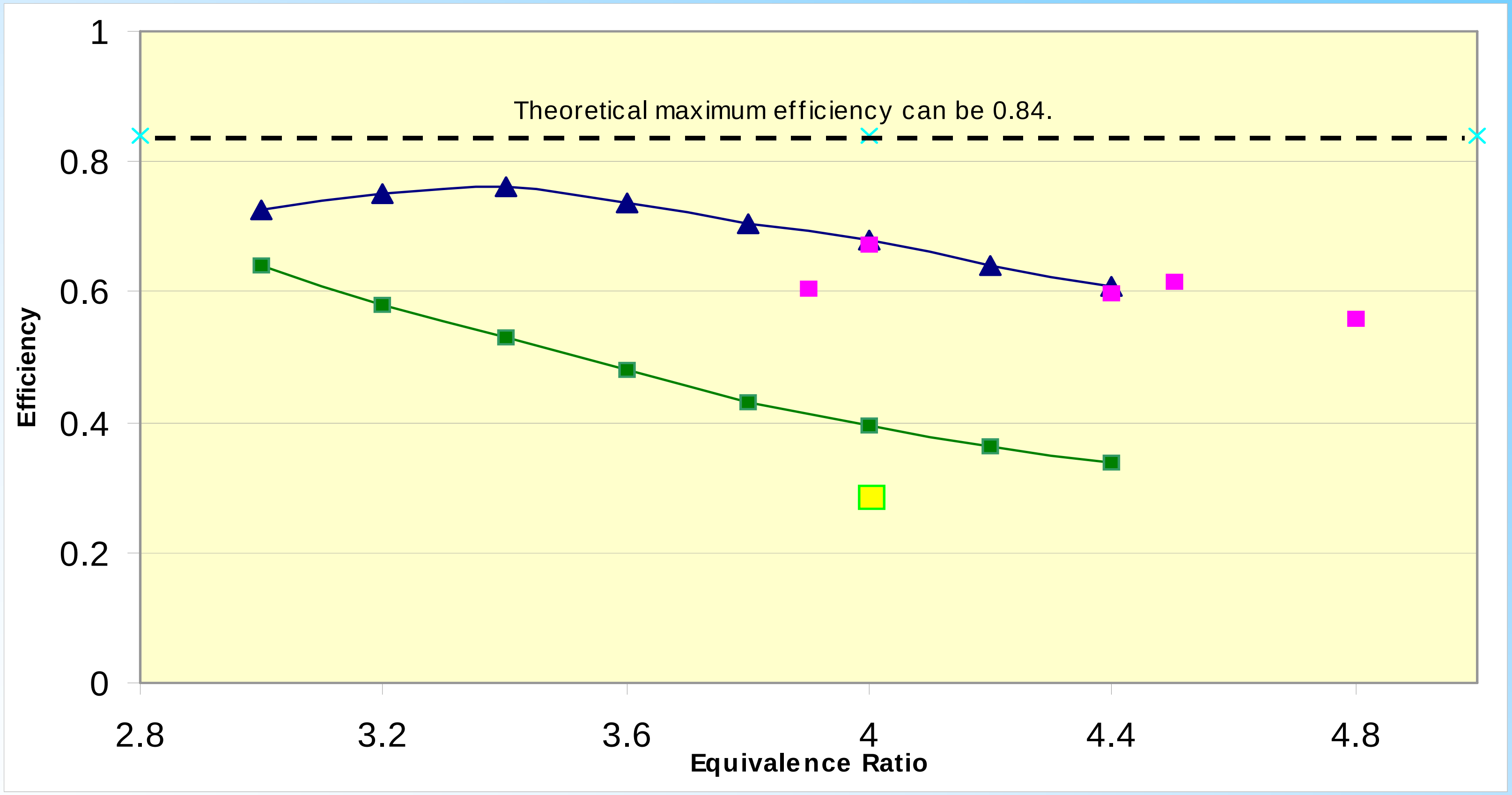
■ Modeling results without plasma

■ Experimental results with plasma

■ Experimental results without plasma

Simulation Vs Experiments

Efficiency = KW-hr of Syn-Gas Produced / Total Energy Input in KW-hr



Modeling results With plasma

Modeling results without plasma

Experimental results with plasma

Experimental results without plasma

Highlights of Plasma-Catalytic Partial Oxidation:

- Only 2.0% of Total Energy Consumption Required for Plasma Power
- Electric Energy Cost 0.06 kWh/m3 of syn-gas (energy from syn-gas = 3.0 KW-hr/m^3).
- 92% conversion at Equivalence ratio of 3.3.
- Internal Heat Recuperation (Preheating) at 750 K.
- No soot Deposition.
- Large Specific Production rates due to low residence times.
- Effective for Higher Hydrocarbon conversion to Syn-Gas.
- Not Sensitive to Sulfur and Other Impurities.

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