*Plasmatron Fuel Reformer Development and Internal Combustion Engine Vehicle Applications**

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Plasmatron Fuel Reformer Development Team

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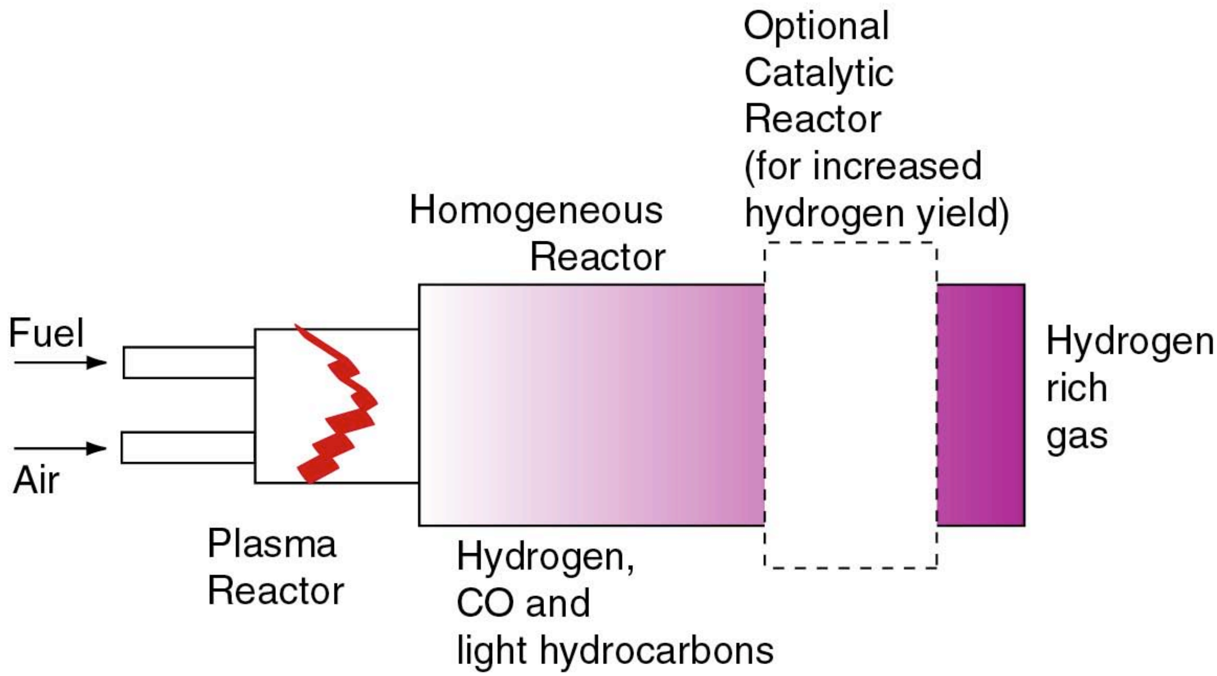
ArvinMeritor

- Commercializing technology licensed from MIT
- NOx exhaust aftertreatment applications (to be presented later in this conference by N. Khadiya)

Potential Uses of Reformer Generated Hydrogen Rich Gas for Diesel Engine Vehicles

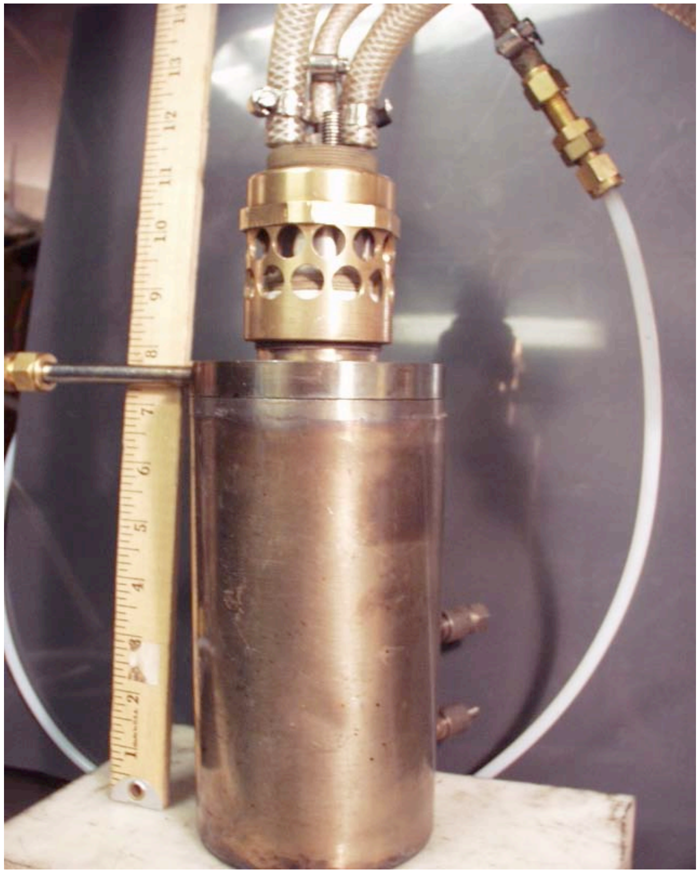
- Exhaust aftertreatment
  - NOx trap regeneration (being commercialized by ArvinMeritor)
  - Controlled regeneration of diesel particulate filters (DPF)
- Bio-fuel conversion
  - Bio-oils
  - Ethanol
- HCCI applications
  - Increased HCCI-operation engine map
  - Control

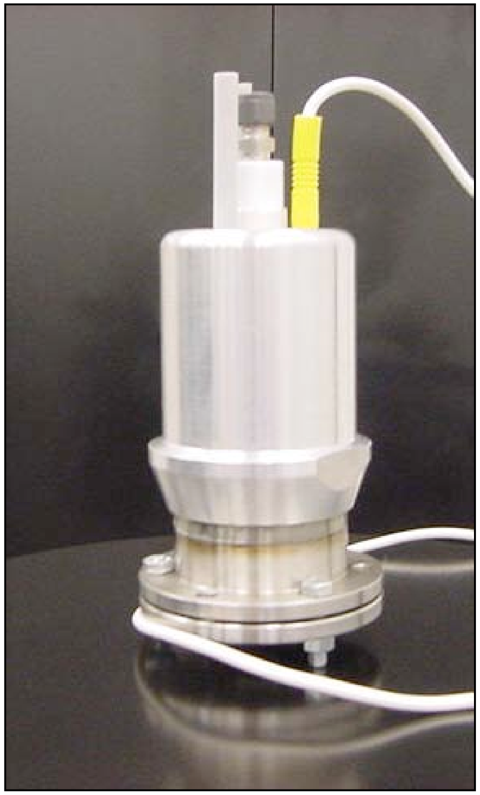
Plasmatron Fuel Reformer



- Advantages:
  - Rapid response
  - Elimination or relaxation of catalyst for reforming
  - Capability to convert difficult to reform fuels

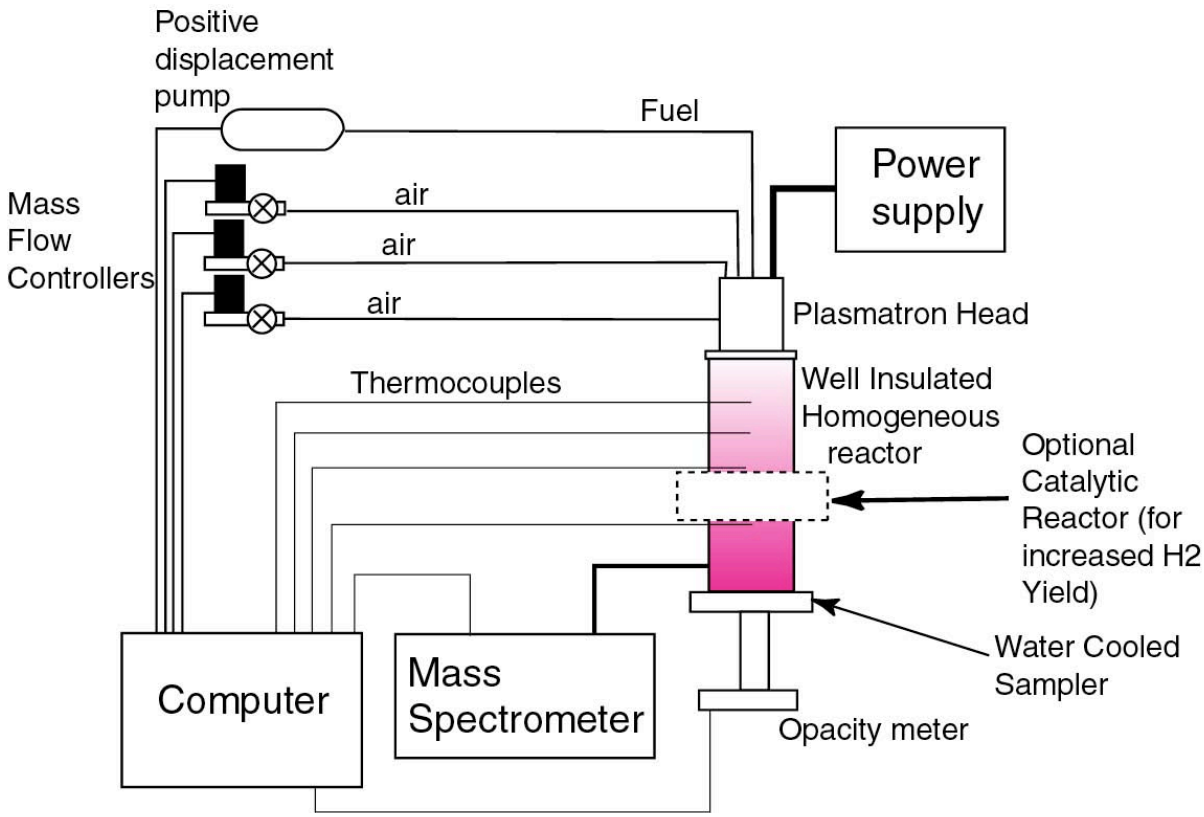
Plasmatron Fuel reformers





Volume of device ~ 2000 cm^3

Plasmatron Fuel Reformer Testing



- Capabilities:
  - Flow control to 100's of ms
  - Sampling rate faster than 200 ms

Mass spectrometer development

- Characterization of response time of entire system
- Development of novel calibration techniques
  - Use ratios of ion currents, instead of absolute calibration
  - Ions that are being considered:
    - Ar (present in air at ~ 1%)
    - N+ (at mass-to-charge ratio of 14)
  - With known flowrates of Ar, N_2, quantitative information of flow rates of gases of interest
  - Separation of N_2 and CO by use of N^+ ion
  - Ability to scan 10 ions in 200 ms for dynamic testing

Diesel Homogeneous Reforming
Experimental results

Electric power	W	200
O/C		1.2
Diesel flow rate	g/s	0.8
Corresponding chemical power	kW	36

Reformate composition (vol %)	
H2	7.6
O2	1.3
N2	64.0
CH4	2.4
CO	13.0
CO2	4.4
C2H4	2.2
C2H2	0.0
H2O	7.1

Energy efficiency to hydrogen, CO and light HC		65%
H2 flow rate	l/min (STP)	20
Soot (opacity meter)		0.0%

NOx Trap Regeneration (ArvinMeritor)

- On-board testing of plasma fuel reformer based H_2 regeneration
  - Demonstrated significant benefits (relative to diesel fuel regeneration)
    - Lower temperature of regeneration
    - Decreased fuel penalty

- Desulfation of traps
  - Lower temperature

- Results to be presented later at this conference:

  A Fast Start-up On-Board Diesel Fuel Reformer for NO_X Trap Regeneration and Desulfation, Navin Khadiya, ArvinMeritor (Sept 2, 2004 9:00 – 9:20 a.m.)

Potential Advantages of Hydrogen Rich Gas Enhanced DPF Regeneration

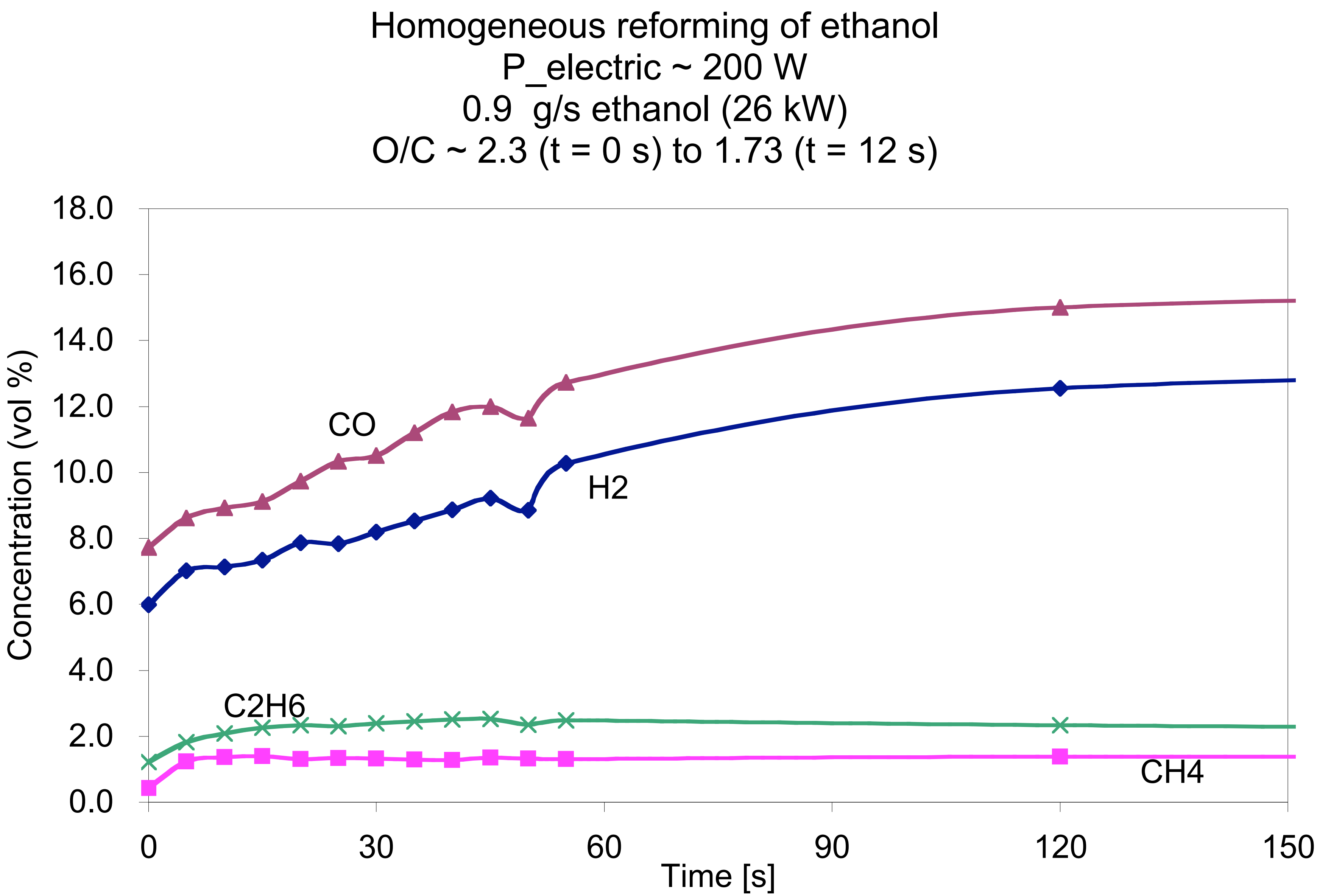
- Hydrogen rich gas could provide important advantages for controlled regeneration of DPF
  - Provide clean burning fuel to initiate and control burnup of soot in trap during regeneration
  - Regeneration at lower soot levels (more frequent regenerations with decreased chance of large uncontrolled burning)
  - Increased reliability and longevity possible
- Tests needed to determine benefits

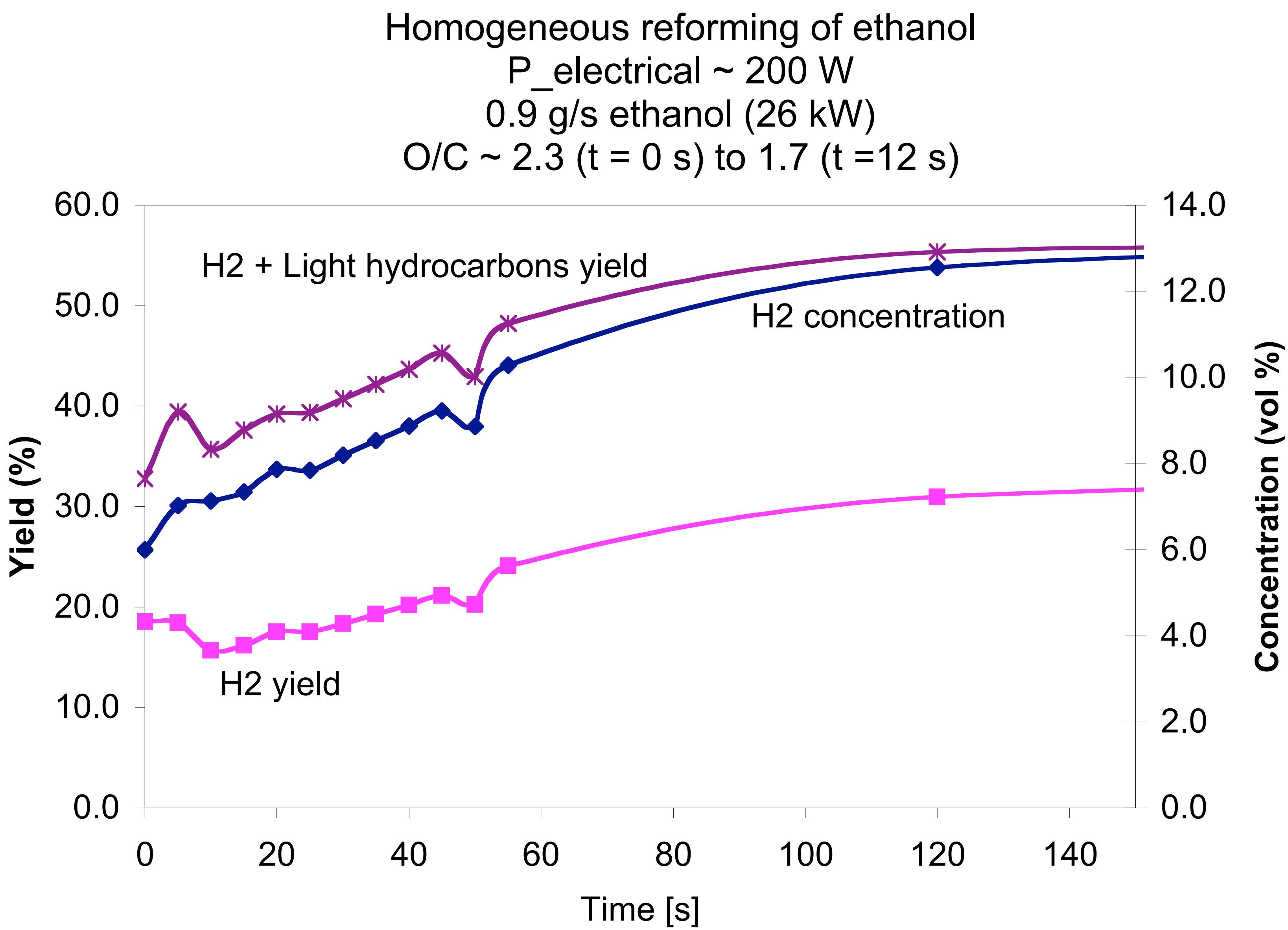
Potential Biofuel Applications

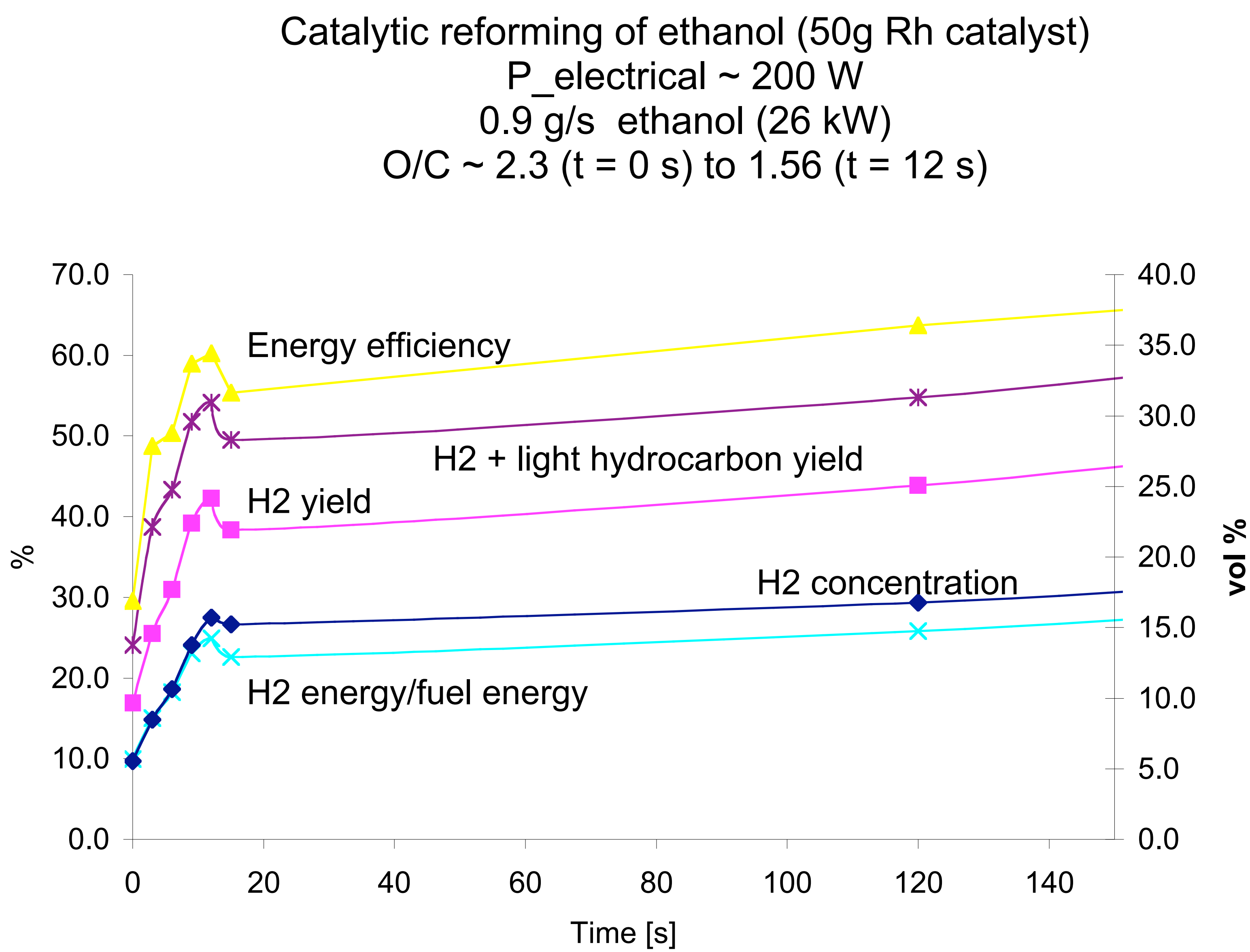
- Reforming facilitates increased use of biofuels
- Bio-oil fueled CI engines with H_2 regeneration of NOx traps and DPF traps
- Facilitates engine use of minimally refined bio-oils
- Facilitate increase use of ethanol
  - Maximize the use of high hydrogen to carbon ratio in ethanol
  - Uses in both SI and CI engine

Biofuel Reforming: Ethanol

- Both homogeneous (non-catalytic) and catalytic reforming tested
- Cold start (room-temperature) testing
  - Investigation of startup optimization by varying ratio of oxygen to carbon (O/C)
- Catalytic reforming tested using Rh catalyst


Homogeneous reforming of ethanol
P_electric ~ 200 W
0.9 g/s ethanol (26 kW)
O/C ~ 2.3 (t = 0 s) to 1.73 (t = 12 s)
Concentration (vol %)
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
CO
H2
C2H6
CH4
0
30
60
90
120
150
Time [s]


Homogeneous reforming of ethanol
P_electrical ~ 200 W
0.9 g/s ethanol (26 kW)
O/C ~ 2.3 (t = 0 s) to 1.7 (t =12 s)
H2 + Light hydrocarbons yield
H2 concentration
H2 yield
Yield (%)
Concentration (vol %)
Time [s]
60.0
50.0
40.0
30.0
20.0
10.0
0.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
0
20
40
60
80
100
120
140


Catalytic reforming of ethanol (50g Rh catalyst)
P_electrical ~ 200 W
0.9 g/s ethanol (26 kW)
O/C ~ 2.3 (t = 0 s) to 1.56 (t = 12 s)
Energy efficiency
H2 + light hydrocarbon yield
H2 yield
H2 concentration
H2 energy/fuel energy
%
vol %
Time [s]
0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
0.0
5.0
10.0
15.0
20.0
25.0
30.0
35.0
40.0
0
20
40
60
80
100
120
140

Ethanol Reforming Results

- Fast turn-on with instantaneous (< 1 s) yield of 32% to hydrogen and light hydrocarbons and 20% to hydrogen using homogeneous reforming
  - Facilitated by fuel vaporization in plasmatron, enlarged volume reaction initiation, enthalpy addition

- 65% energy conversion to H_2 and light hydrocarbons (not including CO) after 120 s

- Plasma catalytic reforming offers opportunities for increased conversion to hydrogen

Reformate composition unrefined soybean oil 0.37 g/s (16 kW) (heavy, viscous) O/C = 1.08

	Homogeneous vol %	Catalytic vol %
H_2	8.1	15.5
CO	11.1	16.6
CO_2	6.7	5.0
N_2	57	53
CH_4	1.2	1.0
C_2H_4	5.1	2.8
C_2H_2	0.1	0.0
O_2	0.6	0.6
H_2O*	9.8	5.3

*Estimated from hydrogen and oxygen balances

Modeling Work

- Fluid codes being used to understand mixing and vaporization of liquid prior to discharge
- Chemkin models are being used to investigate the chemistry in the presence of non-uniform mixtures and turbulence (mixing)
- Models predict trends of methane partial oxidation
- Models being developed for ethanol and liquid hydrocarbons (gasoline, diesel)

Summary

- Onboard generation of H_2-rich gas can provide important benefits for diesel engine exhaust aftertreatment.
- Plasmatron fuel reformer is promising technology for practical onboard generation of H_2-rich gas.
- Plasma fuel reformers can facilitate increased use of biofuels