Onboard Plasmatron Generation of Hydrogen rich Gas for Diesel Aftertreatment and Other Applications*

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Diesel Engine Emissions Reduction(DEER) Meeting

August 2002

*Work supported by US DoE Office of Transportation Technology, Dr. S. Diamond

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Diesel Plasmatron Reformers

- Enhanced conversion of diesel fuel into hydrogen rich gas (H_2 + CO)
- Electric discharge (plasma) continuously applied to flowing fuel/air mixture
- Plasma boosts partial oxidation reaction that reforms hydrocarbon fuels into hydrogen-rich gas

  partial oxidation (at oxygen/carbon ratio=1):

  $$C_nH_m + \frac{n}{2}O_2 = nCO + \frac{m}{2}H_2$$

  Exothermic reaction

  For diesel:

  $$C_{15}H_{25} + 7.5\ O_2 \rightarrow 15\ CO + 12.5\ H_2$$

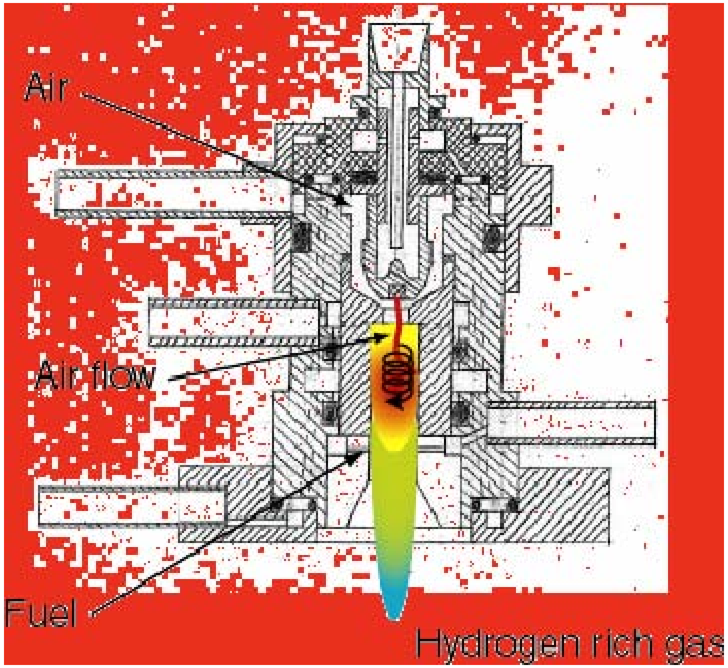
  ~15% of energy released

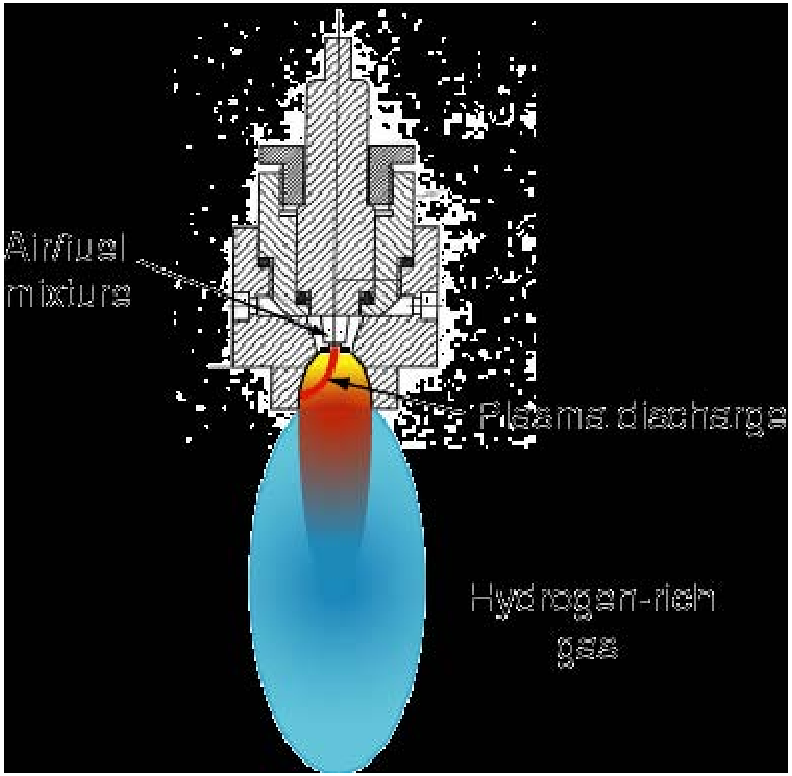
- Plasmatron can boost conversion into hydrogen rich gas by
  - Production of reactive species throughout incoming fuel mixture
  - Mixing of reactants
  - Significantly increasing temperature

Plasmatron Reformers

- Continuous large volume reaction initiation at entrance to reformer
- Fuel gasified at entrance to reformer
- Uniform large volume reaction initiation
  - Radicals
  - Local high plasma energy regions
  - Improved mixing through plasmas induced turbulence
- Conversion reactions occur over whole reformer volume facilitating high conversion efficiency in small volume
- Soot decreased
- Additional enthalpy (for startup, transients) can be instantaneously provided

Diesel plasmatron design evolution





DC arc plasmatron (thermal plasma)

High current, high power, water cooled electrodes

Circa 1999

Low current plasmatron (nonequilibirum plasma)

Low current, low power, long electrode lifetime

Circa 2001

Benefits of Diesel Plasmatron Operation

- Capability to robustly reform diesel fuel, a difficult to reform fuel, in compact device
- High power conversion efficiency (conversion of diesel into hydrogen and other fuels) without use of reforming catalyst (but with relatively modest hydrogen yields)
- Minimization of catalyst requirements when catalyst is used (catalyst may be used to increase the hydrogen yield)
- Rapid startup of hydrogen production
- Reliable hydrogen production under changing conditions
- Flexibility in reformer operating regime
- Operation with other difficult to convert fuels (biofuels)

MIT Microplasmatron Reformer*
*sponsored by USDOE

Low current plasmatron head

Diesel plasmatron reformer

Illustrative parameters for low current device

Power	W	300-600
Plasma Current	A	.1-.4
H2 flow rate	slpm	40
Length	cm	40
Volume	cm^3	2000
Weight	kg	3

Biofuel reforming

- Results with DC arc plasmatron reformer

	CANOLA	CORN OIL
Fuel flow rate (g/s)	0.3	0.47
Hydrogen concentration (% vol)	25.6	23
Methane concentration (% vol)	1.7	7.6
Carbon Monoxide concentration (% vol)	26	18.6
Carbon Dioxide concentration (% vol)	0.3	2.1
Hydrogen yield	92%	84%

- Goal is to get similar results with non-equilibrium plasmatron reformer

Potential Exhaust Aftertreatment Applications

- NOx absorber catalyst regeneration
- HC SCR aftertreatment
- Onboard ammonia manufacturing

NOx Absorber Catalyst Regeneration using Diesel plasmatron reformer

- Hydrogen rich gas is a significantly stronger reducing agent than diesel, useful for NOx regeneration
  - Lower temperature regeneration possible
  - Reduced loss in overall fuel efficiency due to lower requirements on amount of reducing gas
  - Shorter regeneration time due to greater reducing capability of hydrogen rich gas and higher concentration of reducing gases.
- Desulfurization at lower temperatures in a reducing atmosphere may be possible
- Reformate is hot, allowing increased temperature control over regeneration process, without the need of free oxygen

Plasmatron fuel converter performance
diesel fuel

		Thermal plasmatron 1999	Low current plasmatron 2001
Electrical power	W	>1500	100-800
O/C ratio		~1	1.2-1.4
Fuel flow rate	g/s	0.6	0.4
Hydrogen yield		0.9	.5-.9
Power conversion efficiency		0.9	0.85
Reformate temperature	K	1200	1000-1300

Reformate composition

2001

	Homogeneous	Catalytic
Concentration		
H2	0.08	0.18
CO	0.15	0.22
C2's	0.03	0.03
Convesion		
H2 in fuel to H2 in reformate	50%	80%
C in fuel to C2's	25%	5%
Power conversion	0.75	0.7
Reformate temperature (K)	1000	850

Light hydrocarbon production for HC SCR

- In homogeneous mode, diesel plasmatron reformers can generate substantial amounts of C2's with high reformate thermal efficiency
  - Can be used for HC SCR (Hydrocarbon selective catalytic reduction)
  - Preliminary (unoptimized) ~30% carbon to C_2's conversion

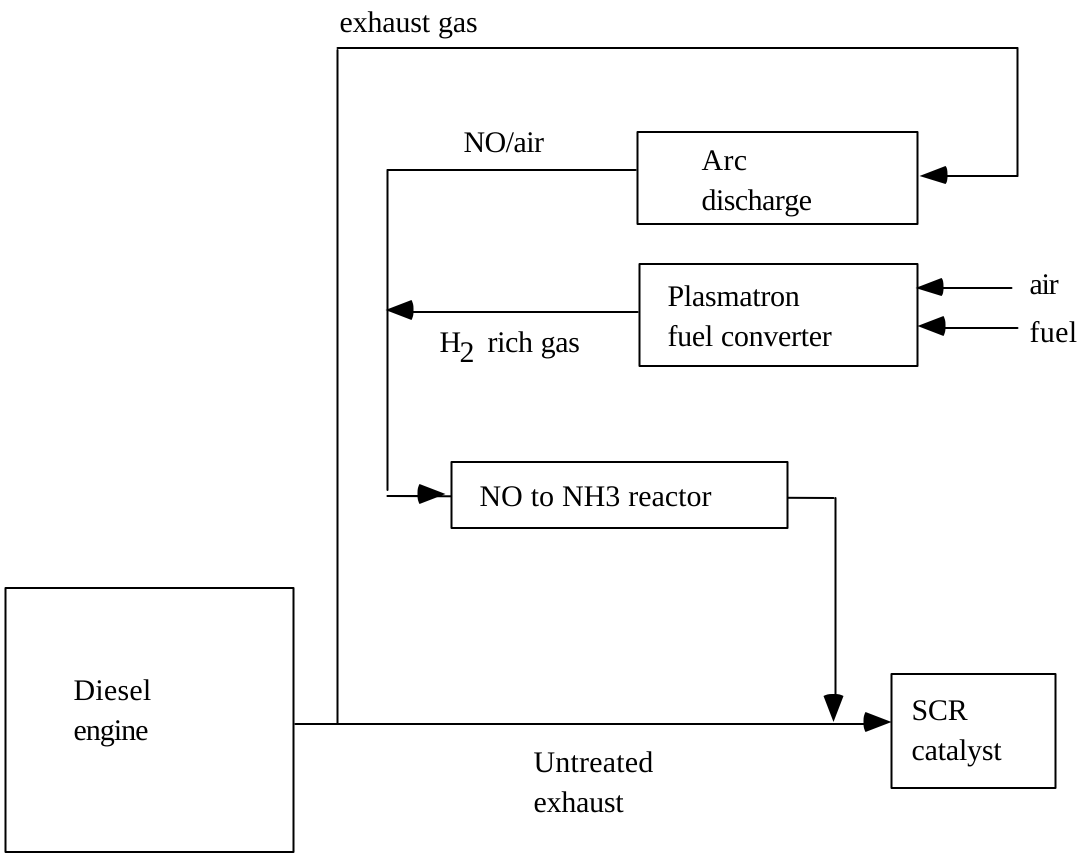
Diesel plasmatron reformer performance (2001 low current plasmatron)

Electrical power (W)		500
Reformate composition		
	H2	9.5
	CO	15.2
	CO2	4.1
	N2	63.5
	CH4	3.4
	C2H4+C2H6	3.1
	C2H2	0.1
Yields		
	CmHn to H2	44%
	CmHn to CO	58%
	CmHn to C2's	28%
Reformate thermal efficiency		88%
Reformate power (HHV, kW)		36

Diesel plasmatron reformer
Onboard ammonia manufacturing

- Two options for manufacturing of ammonia using diesel plasmatron reformers are:
  - Ammonia from synthesis gas (N_2, H_2 --> NH_3)
  - Ammonia from onboard NO (NO, H_2 --> NH_3)
- The practicality of using these processes is uncertain. Proof of principle experiments for these options have not been performed.

Ammonia from NO



Nonthermal plasma production of ammonia

- Speculative approach
  - However, recent publication shows promise
    - Limited conversion has been demonstrated
    - need to improve yields

- Hydrogen production well characterized
- Nonthermal plasma process can be described by:

η: the electrical energy cost in the reactor (energy spent per ammonia molecule

ε: the hydrogen conversion (amount of hydrogen that is converted to ammonia).

Diesel plasmatron reformer
Present status

- Substantial improvements relative to first generation (point electrode) low current plasmatron reformer design
- Homogeneous (non-catalytic reforming) can produce relatively high H2 and light hydrocarbons yields, with high power conversion efficiency
- Efficiency comparable to ideal partial oxidation (power conversion efficiency ~80%)
- High flow rates can be reliable obtained
    - Up to 1 g/s fuel (about 40 kW reformate heating value)
- Larger surface area in recent designs
    - Provides long electrode lifetime.
- Relatively low electrical power consumption (300-600 W)

Diesel plasmatron reformer
Future improvements

- Fast response time under various conditions
  - Start up
- Plasma catalysis optimization for maximum hydrogen production
- Soot free operation over wide range of conditions
- Increased diesel fuel throughput
- Optimum flow rate and response capability for various applications
- Reduced electrical power consumption

Summary

- Plasmatron reformers can provide substantial advantages in converting diesel fuel and other difficult to reform fuels (e.g. biofuels) into hydrogen rich gas
- Diesel plasmatron generated hydrogen rich gas could significantly improve prospects for successful use of NOx traps
- Diesel plasmatron technology could also be used for HC SCR and onboard ammonia production applications
- Significant progress in the performance of diesel plasmatron reformers has been made in the past year.