Onboard -Plasmatron Hydrogen Production

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Argonne National Laboratory
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ArvinMeritor

Team

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- **ARVINMERITOR**
  - Tier 1 US automotive and heavy truck components manufacturer
  - Commercializing plasmatron technology licensed from MIT
  - S. Crane, N. Khadiya, R. Smaling et. al

Plasmatron Reformer Technology

- Compact technology for production of hydrogen -rich gas
  - Special low power plasma promotes partial oxidation conversion of gasoline, diesel, bio oils, and other fuels to hydrogen-rich gas
- Advantages:
  - Fast startup and rapid response to transient conditions
  - Relaxation or elimination of reformer catalyst requirements
  - Compact
  - Efficient
  - Robust capability for onboard multi-fuel reforming (can process difficult to reform fuels, e.g. diesel, bio-oils, ethanol)

Potential Applications

- Enhanced diesel engine exhaust aftertreatment using hydrogen rich gas
  - NOx emissions reduction (regen of NOx traps, hydrogen SCR)
  - Particulate emissions reduction (regen of diesel particulate filters)
- Alternative fuel conversion to hydrogen-rich gas (bio-oils, ethanol)
- HCCI engines using diesel and other fuels
- Hydrogen enhanced spark ignition engines
  - ultra-lean operation
  - Improved efficiency
  - Further reduction of emissions

Accomplishments

- Plasmatron technology transferred to industry (ArvinMeritor) for commercialization
- DOE investment in plasmatron technology has been leveraged into a much greater development effort by industry
- Plasmatron technology was recipient of the 1999 Discover Award for Technological Innovation in Transportation (in competition with Toyota Prius hybrid vehicle)

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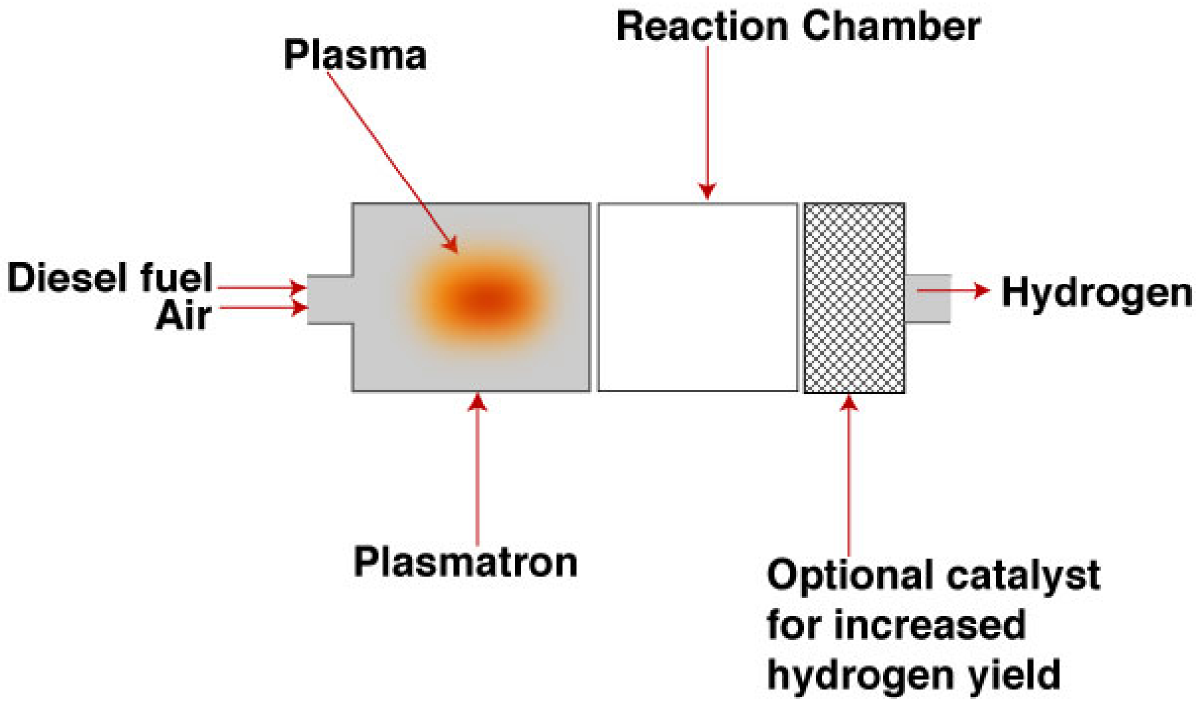
Hydrogen-Rich Gas Production Using Partial Oxidation Reforming

- Add sufficient oxygen from air to bind all carbon in fuel as CO; for iso-octane (representative of gasoline)

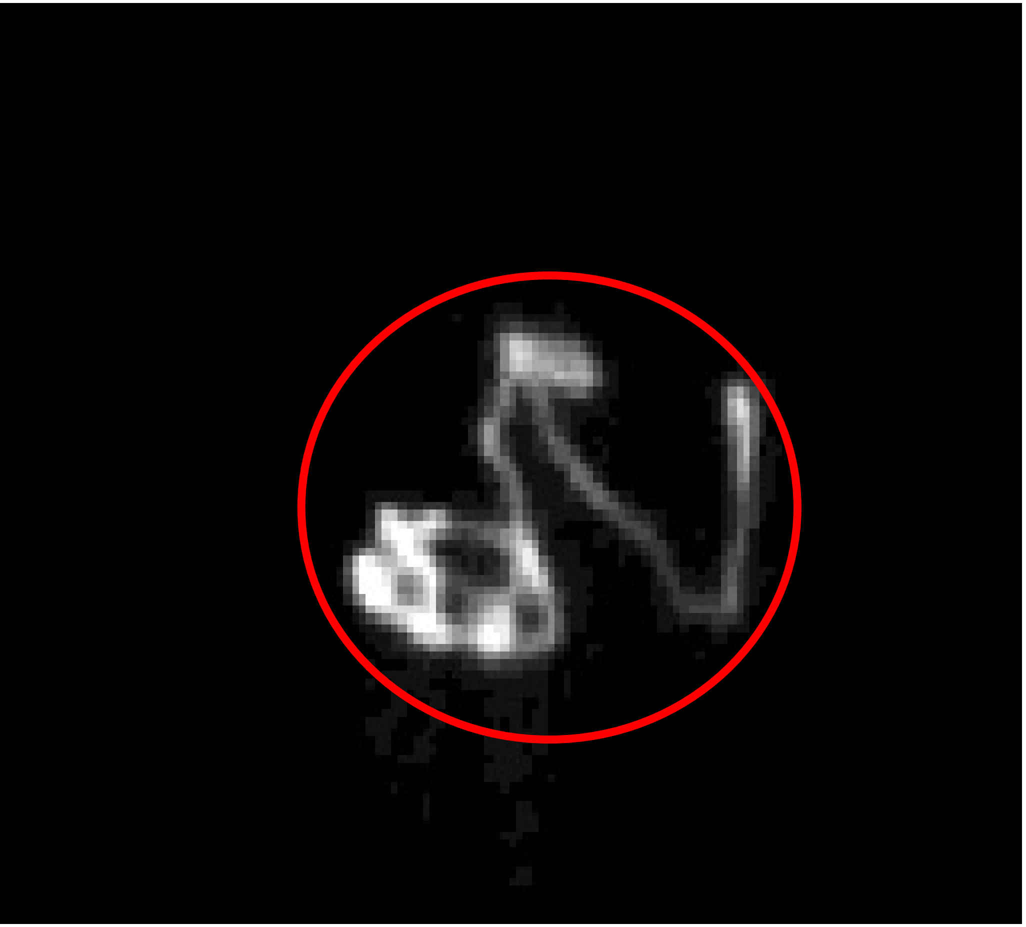
$$C_8H_{18} + 4\ (O_2 + 3.8\ N_2) \dashrightarrow 8\ CO + 9\ H_2 + 15.2\ N_2$$

- Reaction is mildly exothermic
  - Slow reaction
  - Approx 15% of energy released in the reformation process
  - Difficult to startup and maintain under transient conditions

Plasmatron Fuel Reformer



<u>Hydrogen Generation Process</u>
Plasma initiates and maintains the chemical reaction which liberates hydrogen from diesel fuel.



END VIEW

- Plasma created in the a gas flow
- Gas flow stretches the plasma
- Plasma extinguishes and re-establishes (1 kHz)
- Discharge over a large volume

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Low current gasoline plasmatron operating parameters

Power	W	250
Plasma current	A	0.1 - 0.4
H2 flow rate	slpm	10-200
Length	cm	40
Volume	liter	2
Weight	kg	3

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Diesel Fuel Reforming

- Heavy fuels reformed into hydrogen and light hydrocarbons
  - Low oxygen content
  - Low or no soot
  - Fast turn-on
- Reformate can be further processed by catalyst
  - Absence of free oxygen minimizes hot spots
  - High hydrogen yield

Diesel reforming without catalyst

Electric power	W	250
O/C		1.1
Diesel flow rate	g/s	0.8
Corresponding chemical power	kW	35

Concentration (vol %)	
H2	8.2
O2	1.4
N2	68.7
CH4	2.6
CO	14.3
CO2	4.7
C2H4	2.4
C2H2	0.0

Energy efficiency to hydrogen, CO and light HC	70%
Soot (opacity meter)	0

Plasma enhanced partial oxidation reforming

- Homogeneous (non-catalytic)
  - Conversion of liquid fuels into gaseous fuels (including hydrogen, CO, methane, ethylene)
- Plasma catalytic reforming
  - Reduced requirement catalyst can be used to further increase the hydrogen yield from homogeneous reforming

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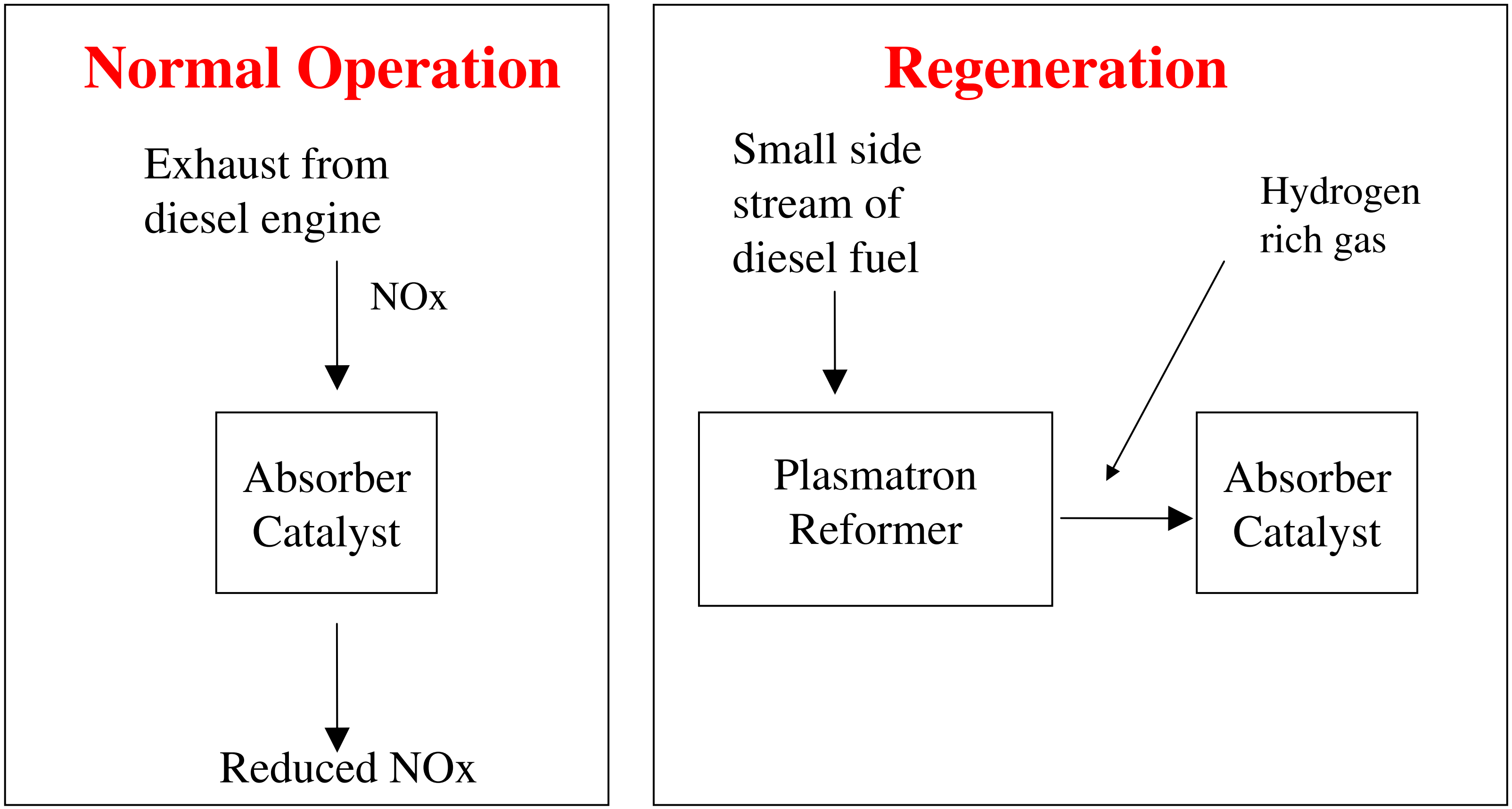
Summary of plasmatron reformer development at MIT

- Effective reformation of a wide variety of fuels: gasoline, diesel, bio-oils ,natural gas
- Fast time response/start up time
  - Virtually instantaneous with reduced yield
- Compact device
  - 2 liters for 100 kW of reformate (hydrogen rich gas)
- Electrical Energy consumption:
  - 1 - 3% of the combustion power of the reformate
- Wide range of operation (factor of 20 hydrogen rich gas output)

Regeneration of NOx trap



Advantages of regeneration with H_2-rich gas:

- Greater effective operating range (lower temperature)
- Reduced fuel penalty
- Reduced adverse effects of sulfur

H_2-Assisted NOx Traps: Test Cell Results Vehicle Installations

Sam Crane

August 28, 2003

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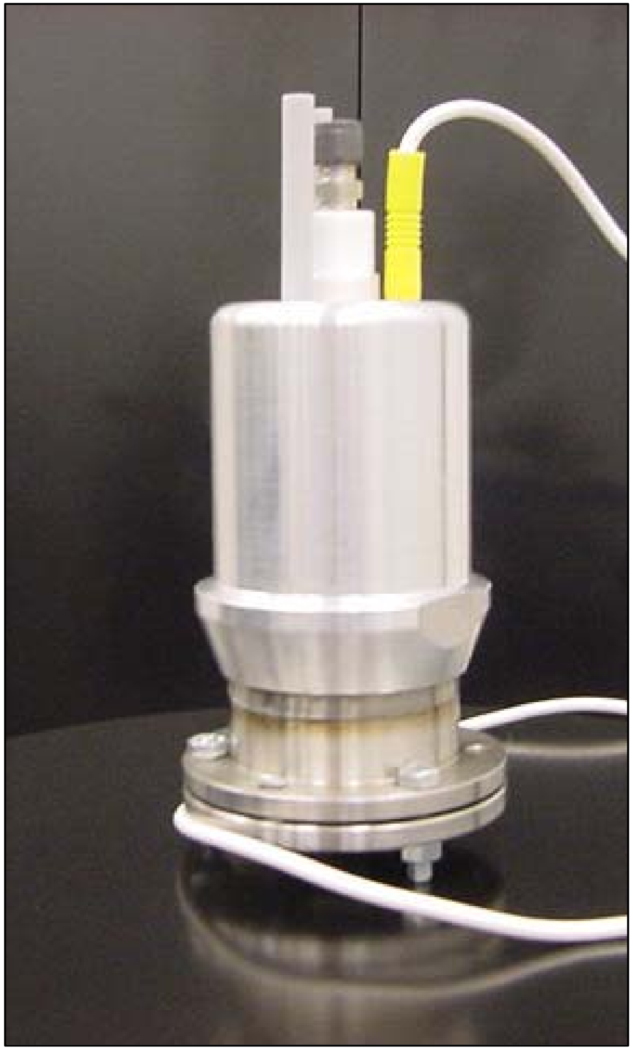
Gen H Fuel Reformer

- After-treatment Suitable
  - Reforms Diesel: 22% H_2
  - Low soot
- Enclosed housing
  - EMI reduced
  - Safety improvement
- New Power Supply
  - Under 250W consumption
  - Minimal heat rejected
  - Compact transformer
- High-temperature flange seals
  - Reduced leakage



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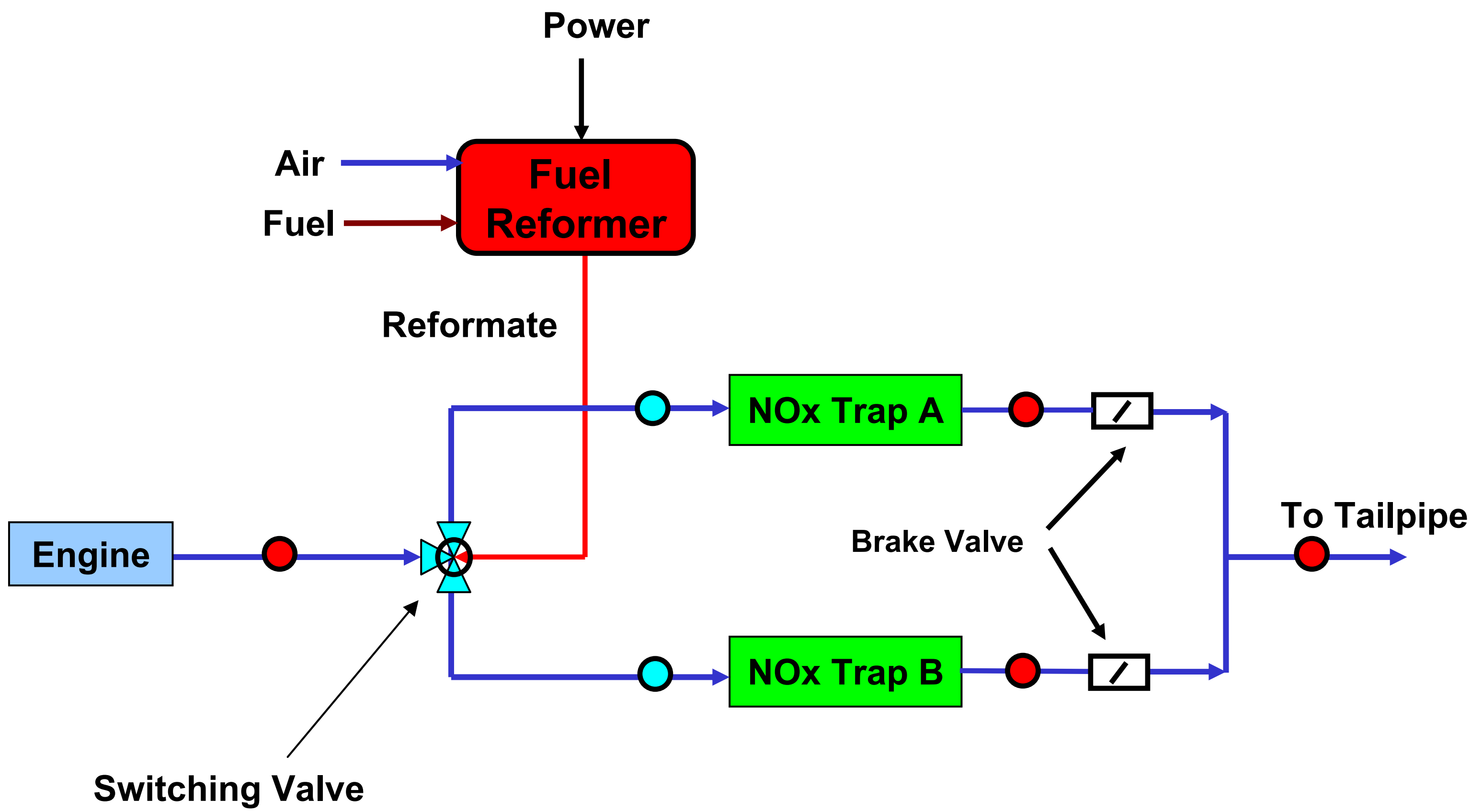
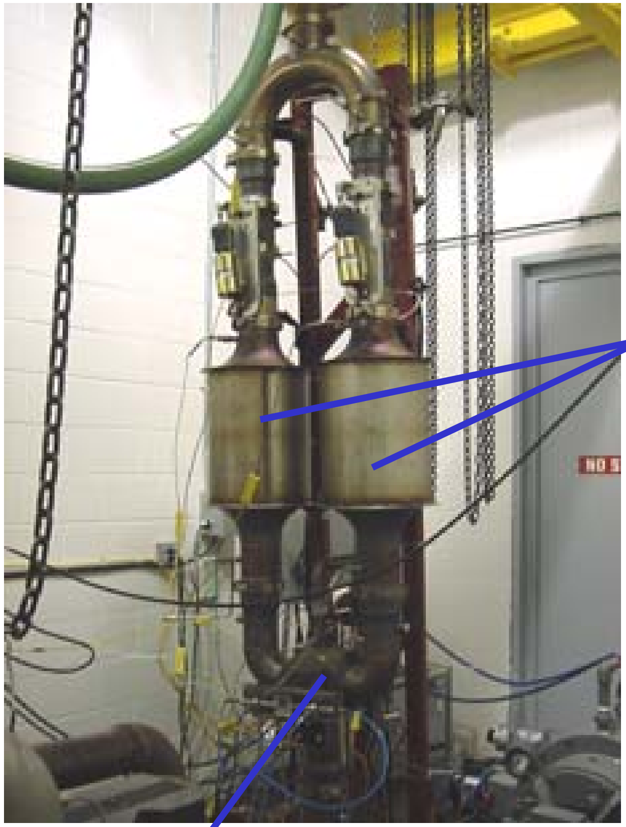
QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

H2-Assisted NOx Trap: Test Set-up



Test Cell Installation: H2-Assisted NOx Trap

Cummins 8.3L MY2000



NOx Traps 14L/leg

Switching Valve

Bus H2-Assisted NOx Trap Installation

Fuel Reformer Box

Access Door

NOx Trap:
21L/leg

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Summary of Results: H2-Assisted NOx Trap

- Regeneration Fuel Penalty Reduction of roughly 50% at moderate exhaust temperatures
- Idle regenerations achieved
- Hydrocarbon slip dramatically reduced
- Dual Leg System installed and operating on a Transit Bus : 80 – 90% NOx Reduction
- Single Leg Bypass System installed and operating on an F250 Truck: 70% NOx Reduction

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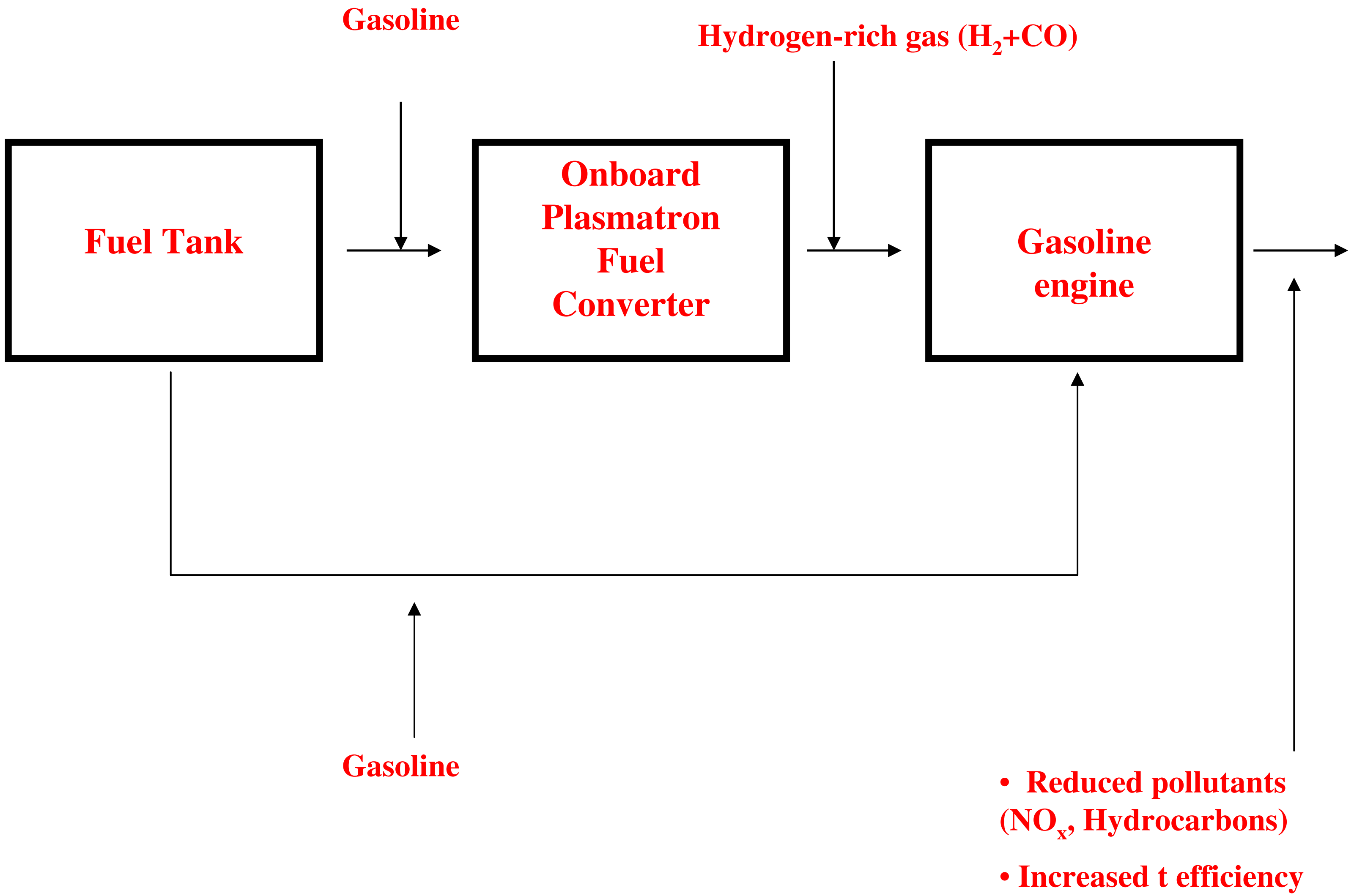
High Efficiency, Low Emission Vehicle Concept



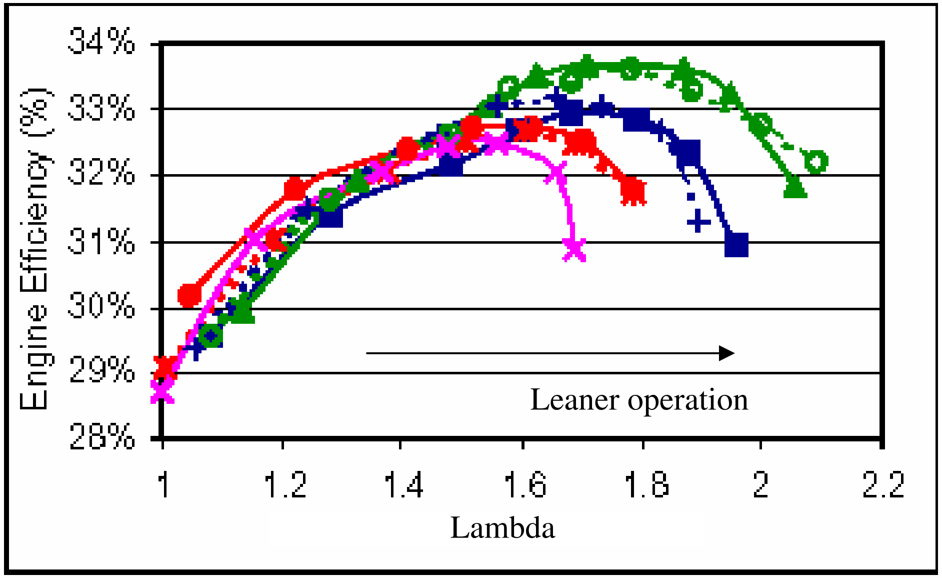


Figure 30: Engine Only Efficiency vs. VDP

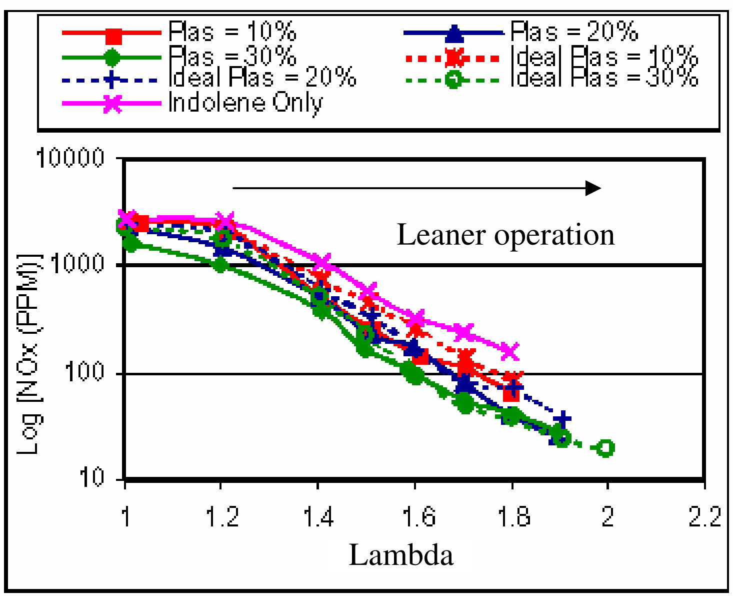


Figure 25: NOx emissions vs. Lambda

Gasoline engine testing at MIT

- Hydrogen enhanced combustion stability allows very lean burn (high air to fuel ratio) without misfire
- Naturally aspirated (no turbocharging) with conventional compression ratio
- Ultralean operation increases efficiency 15% and decreases NOx by a factor of 100

SAE-2003-01-0630

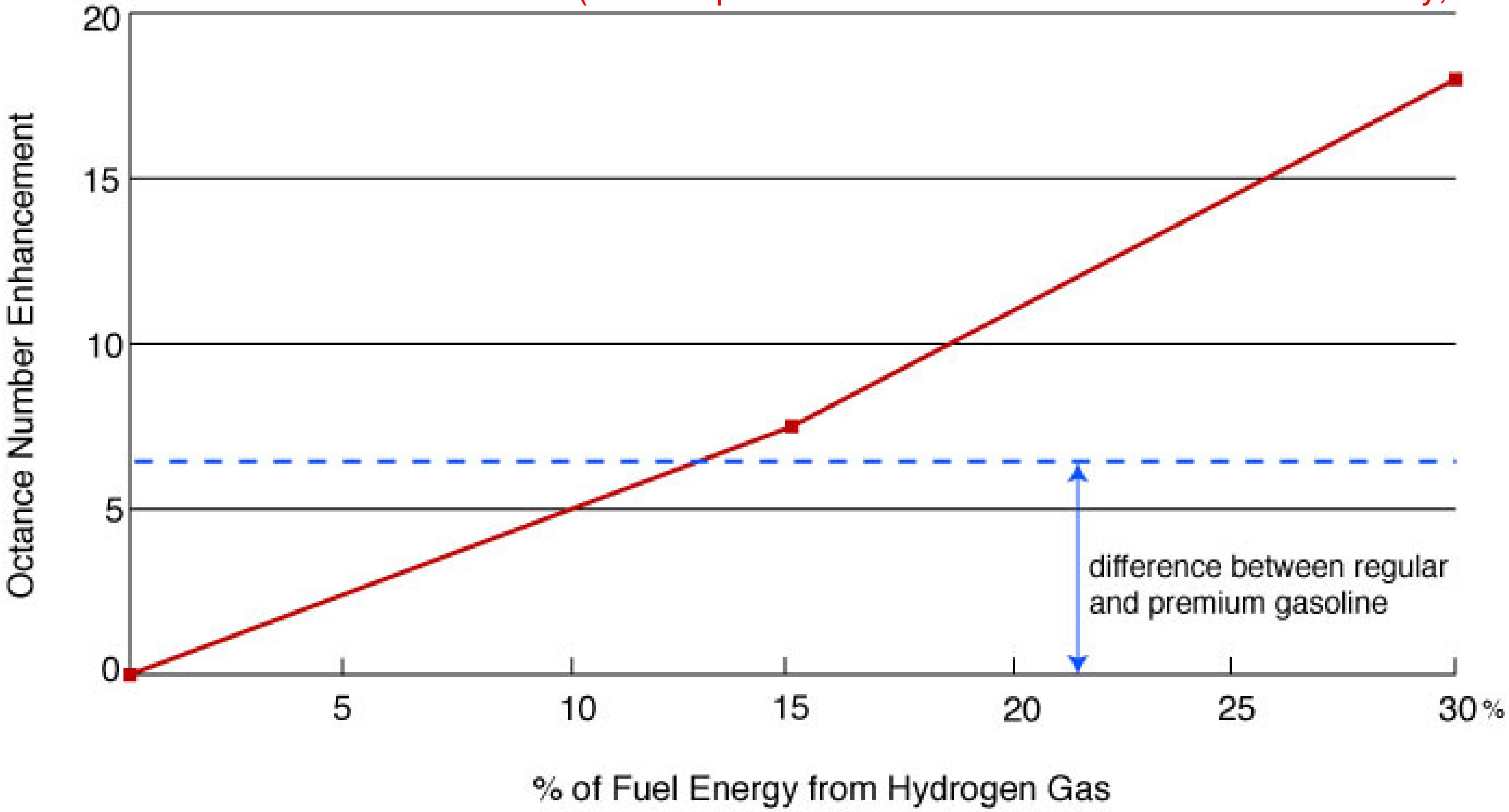
Lean burn characteristics of a gasoline engine enriched with hydrogen rich gas from a plasmatron fuel reformer

E. Tully and J.B. Heywood

MIT Dept. of Mechanical Engineering and Sloan Automobile Laboratory

Octane Enhancement from Hydrogen Addition

(From experiments at MIT Sloan Automotive Laboratory, 2003)



High Compression Ratio, Highly Turbocharged Operation through Improved Knock Resistance

- MIT experiments show that knock resistance is substantially improved by moderate addition of hydrogen rich gas to gasoline (15 octane number increase)
- The combination of enhanced knock resistance and enhanced combustion stability could increase net efficiency by up to a factor of 1.3

Future Directions

- Reformer enhanced regeneration of diesel particulate filters
- Hydrogen SCR for NOx aftertreatment
- Control of HCCI engine operation
- Use with fuel cell for auxiliary power in diesel trucks
- Emission reduction and higher efficiency in spark ignition engines