

# Emerging Technologies for Controlling Marine Engine Emissions

Presented to:

*Conference on  
Marine Vessels & Air Quality*

*By*

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## Introduction

- x SwRI
- x Emerging technologies
  - Near term
    - » Electronic engine management
    - » Fuel composition
    - » Exhaust aftertreatment
    - » EGR
  - Long term
    - » Water-fuel emulsion
    - » Alternative fuels
    - » HCCI
- x Closing thoughts



# Southwest Research Institute

Located in San Antonio, Texas



Founded 1947

~2,700 employees, 170 buildings on 1,200 acres

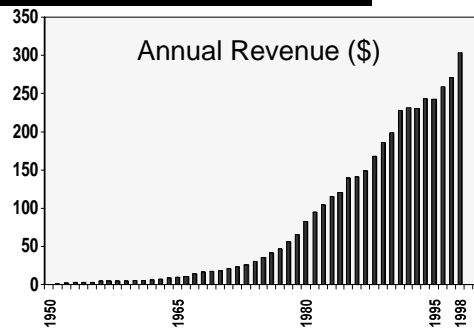
1.7 million sq ft of office & lab space (185,000 m<sup>2</sup>)

FY 1999 revenue over \$308 million



# Southwest Research Institute

- x Best described by what SwRI is ***not***:
  - Not a Government lab
  - Not associated with any University or Industry
  - Not publicly held
- x SwRI is not-for-profit
- x Focused contract R&D
- x Unique patent policy
  - 37 Patents in 1998
- x 50 / 50 mix (commercial / government)



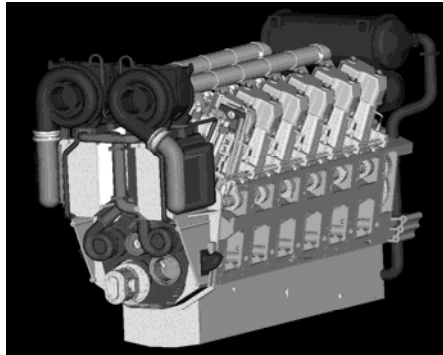
- x SwRI is divided into 11 technical divisions



## Division 03

### *Department of Engine Research*

- x Engine Testing
  - Emissions
  - Performance
  - Fuel economy
- x Engine Development
  - Alternative fuels
  - Performance
- x Engine Design
  - Design
    - » Component & clean sheet
  - Analysis



- x Strong focus on quality

- ı ISO-9001 certified

- ı Ford Q1 status



## Near Term Solutions

- x Electronic engine management
  - Injection equipment
- x Diesel & heavy fuels
- x Exhaust aftertreatment
- x Exhaust Gas Recirculation (EGR)



# Near Term Solution

## *Electronic Management*

### x Injection Equipment

- Electronic controlled jerk pumps (EFI)
- Electronic controlled unit injectors (EUI)
- Common rail (CR)

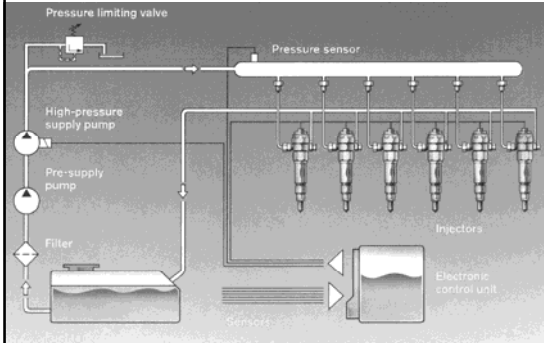


Photo from [www.Boschusa.com](http://www.Boschusa.com)

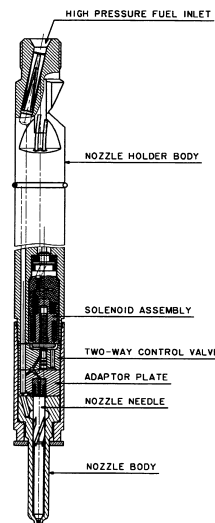


# Near Term Solution

## *Electronic Management (cont'd)*

### x Injection Equipment (cont'd)

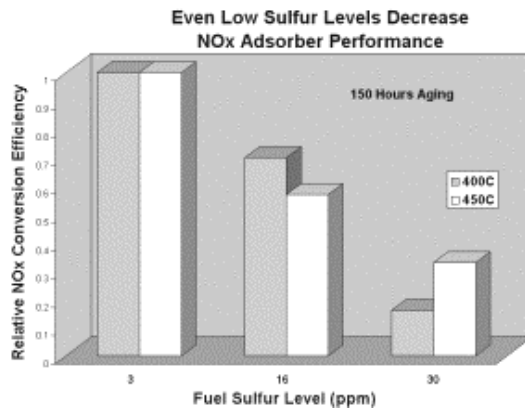
- Injection rate shaping for
  - » Improved performance
  - » Improved fuel economy
  - » Emissions reduction
  - » Improved catalyst operation
- Pilot Injection
- Post Injection
- Common rail provides full authority injection timing & duration (not cam limited)



# Near Term Solution

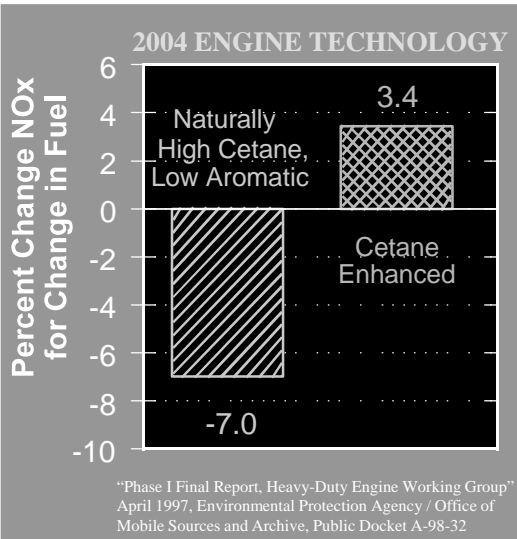
## Diesel and Heavy Fuels

- x Low sulfur fuels
  - PM reduction
  - SO<sub>2</sub> reduction
  - Near 0% sulfur required for NO<sub>x</sub> catalyst
- x High cetane fuels
- x Fischer-Tropsch fuel
  - Produced from NG
  - High cetane
  - Very low sulfur



# Near Term Solution

## Diesel and Heavy Fuels (cont'd)



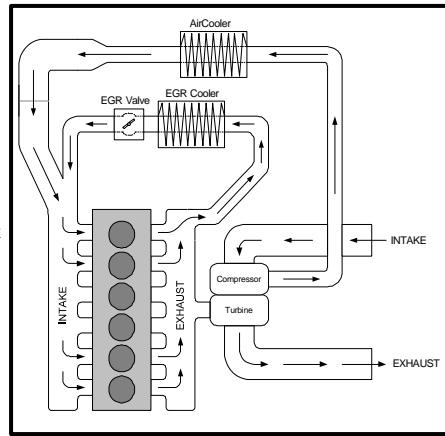
- x Some cetane enhancing additives can increase NO<sub>x</sub> emissions



# Near Term Solution

## EGR

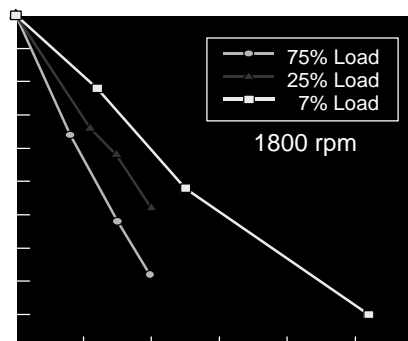
- x Used in
  - Automotive applications
  - On-highway diesel engines
- x Reduces NO<sub>x</sub> emissions in diesel engines
  - Cool EGR desired for max. NO<sub>x</sub> reduction
  - Additional cooling required
  - Additional plumbing and heat exchangers



# Near Term Solution

## EGR (cont'd)

- x Can have adverse effect on PM emissions
  - Oil contamination with soot
  - Wear issues
  - Deposits



# Near Term Solution

## *Exhaust Aftertreatment*

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- x PM Traps
- x Oxidation Cat
- x SCR

Technology	PM Reduction	NO <sub>x</sub> Reduction	HC Reduction	CO Reduction
Diesel particulate filter	>90%	n.a.	>90%	>90%
Diesel oxidation catalyst	>30%	n.a.	>90%	>90%
Selective catalytic reduction	>30%	>90%	>70%	>50%

- x Watch for:
  - Lean NO<sub>x</sub> catalyst
  - Lean NO<sub>x</sub> trap
  - Non-thermal plasma reactor



# Long Term Solutions

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- x Water-fuel emulsion
- x Electronic Valve Actuation (EVA)
- x Alternative fuels
  - Lean burn
  - Stoic combustion
- x Synthesis Gas
- x Homogeneous Charge Compression Ignition (HCCI)



# Long Term Solutions

## *Water Fuel Emulsion*

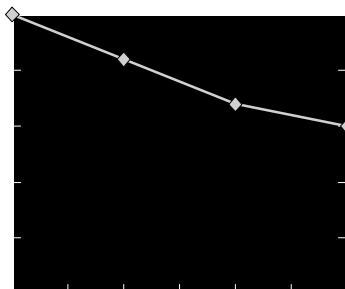
- x Water-fuel emulsion can reduce
  - NO<sub>x</sub> emissions
  - PM emissions
- x Increase fuel economy
- ú ***All of these benefits can be accomplished simultaneously - If done right!***
- x The water
  - Reduces soot formation (PM emissions)
  - Cools the combustion flame (NO<sub>x</sub> formation)
  - Phase change & chemistry = improved efficiency



# Long Term Solutions

## *Water Fuel Emulsion (cont'd)*

- x Injector design modifications often required
- x For steady state operation
  - Homogeneous mixture of fuel & H<sub>2</sub>O
  - Surfactant to keep the water in suspension
- x For transient operation
  - Cycle-by-cycle (or real time) control of water injection for best results
- x Water supply required (filtered and deionized)



6 Liter engine, 2000 rev/min, 80% Load



# Long Term Solutions

## *Electronic Valve Actuation*

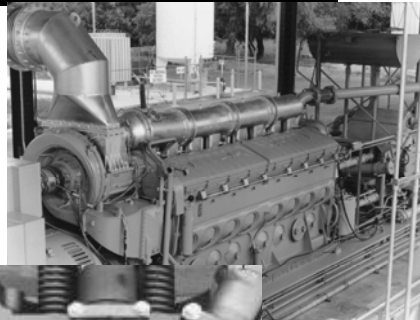
- x Electronic Valve Actuation
  - Can be used for Miller Cycle
    - » Minimize emissions
    - » Maximum performance
  - Variable CR
    - » Better cold starting
    - » Reduced white smoke
  - Use with aftertreatment control exhaust temperature
    - x Catalyst light off
    - x Control catalyst regeneration
    - » Exhaust gas preparation
      - x Catalyst efficiency



# Long Term Solutions

## *Alternative Fuels*

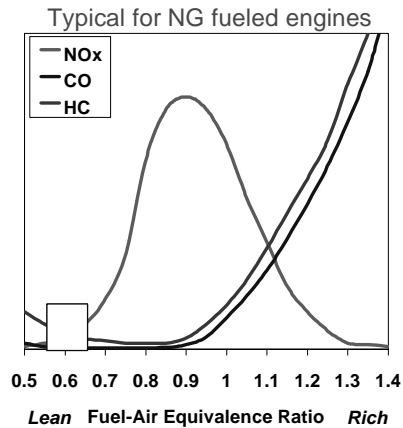
- x Fuels of key interest
  - Natural Gas (NG)
  - Propane
  - Hydrogen
- x NG (as CNG or LNG) most practical and cost effective
- x Some work already done on large engines used in LNG transports



# Long Term Solutions

## *Lean Burn Engines*

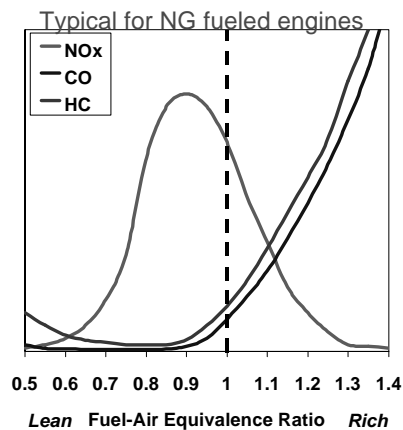
- x Heavy use in stationary & HD on-highway engines
- x Lean Burn = low emissions & good fuel economy
- x Can be used on any of the Alt fuels listed
- x Note box on graph
  - Low NO<sub>x</sub>
  - Low CO
  - Low HC



# Long Term Solutions

## *Stoic Fueled Engines*

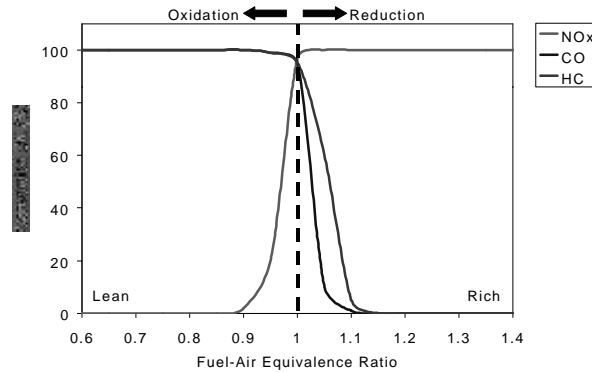
- x Chemically correct A/F ratio
- x Works with NG & LPG fuels
- x Not feasible for hydrogen
- x Fuel economy less than lean burn
- x High combustion and exhaust temperatures
- x Allows use of three way catalyst
  - Very low emissions
- x Exhaust Gas Recirculation (EGR) used for dilution



# Long Term Solutions

## *Stoic Fueled Engines (cont'd)*

### Catalyst Conversion Efficiency



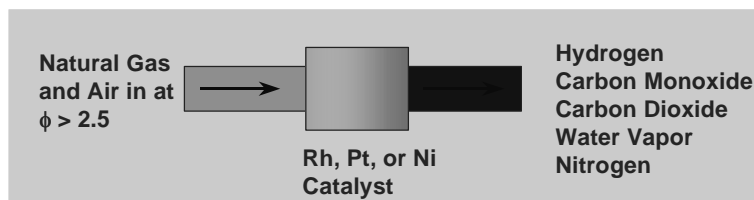
- × Accurate control of A/F ratio required to maintain catalyst efficiency



# Long Term Solutions

## *Synthesis Gas*

- × Also known as “Syngas”
- × Hydrogen source for combustion enhancement
- × H<sub>2</sub> produced by rich combustion of natural gas and air over catalyst (low soot)



# Long Term Solutions

## Synthesis Gas (cont'd)

Advantages of synthesis gas when used with:

### Lean Burn Engine

- ε H<sub>2</sub> can extend lean limit
  - Much cheaper than SCR on lean-burn

### Stoichiometric Engine

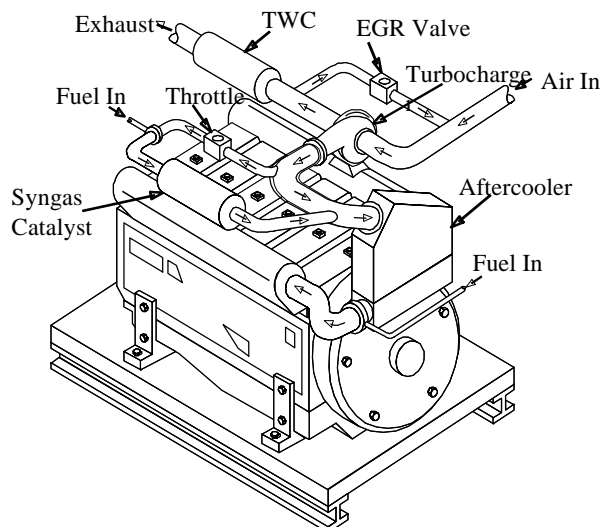
- ε H<sub>2</sub> extends EGR tolerance
  - EGR tolerance increased by up to 44%
  - High EGR dilution rates provide:
    - » Reduced exhaust temp to lean-burn levels
    - » Increased power density
    - » Reduced engine-out NO<sub>x</sub> by 77%
  - Use TWC to reach NO<sub>x</sub> <15 ppm



# Long Term Solutions

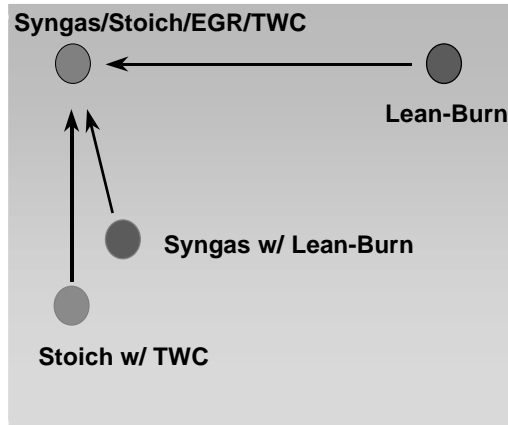
## Synthesis Gas (cont'd)

x Syngas for Stoic Engine w/EGR



# Long Term Solutions

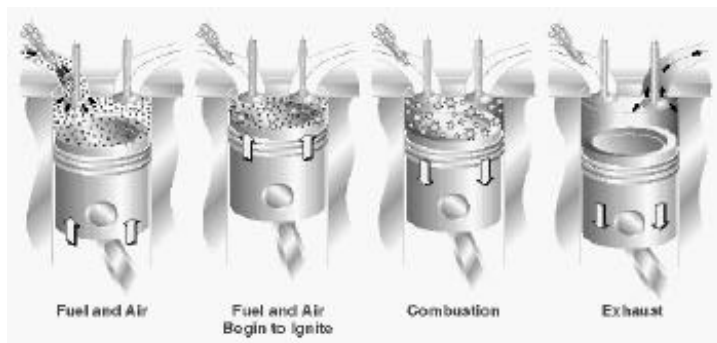
## *Synthesis Gas (cont'd)*



# Long Term Solutions

## *HCCI*

- x What is HCCI?
  - Homogeneous mixture of fuel (or fuels) & air
  - Compression ignition



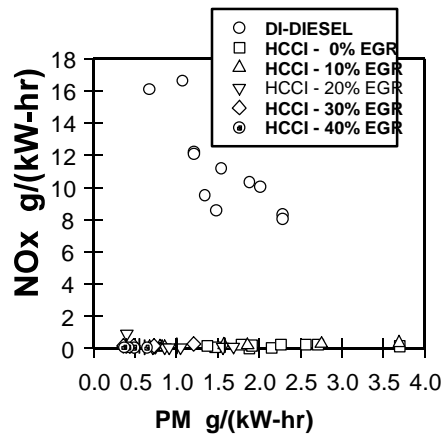
- x Spontaneous reaction throughout cylinder
- x Low temperature reaction creates low  $\text{NO}_x$



# Long Term Solutions

## HCCI (cont'd)

- × Used to produce ultra low  $\text{NO}_x$  emissions
  - 95% reduction from diesel levels
- × High efficiency
  - Near diesel levels while producing low emissions
- × Issues
  - Control start of combustion
    - » Has been demonstrated by using 2 fuels
  - Full load
    - » Laboratory engine at 35% of peak torque



# Closing Thoughts

- × Keep informed!
  - Conferences
    - » Upcoming example
      - × ASME, ICE Division
        - 2001 Spring Technical Conference (April 29 – May 2, 2001)
        - Host - **U.S. Navy Surface Warfare Center, Philadelphia, PA**
  - Web sights
    - » [www.asme.org/divisions/ice](http://www.asme.org/divisions/ice)
    - » [www.sae.org](http://www.sae.org)
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