



Cutting NOx from Diesel Engines with Membrane Generated Nitrogen Enriched Air

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NOx Emissions Reduction

- NOx, oxides of nitrogen, formed during combustion
- Particularly high temperature combustion
- Reducing combustion temperature reduces NOx
- Dilution of engine cylinder charge with inert gases lowers temperature and thereby reduces NOx
- Possible diluents
 - nitrogen
 - carbon dioxide
 - exhaust gases
 - water vapor or steam

The CMS approach ...

- Nitrogen Enriched Air (NEA)
- from cooled turbocharged air
- with an air separation membrane
- integrated into the diesel engine
- for on-road, nonroad, locomotive and marine diesel powered equipment

Air Separation Membranes

- Gas molecules absorb in polymer skin
- Then diffuses through the membrane
- And desorb from opposite surface
- Migration driven by partial pressure diff.
- Gas species transport at different rates.

H₂O, H₂, He, H₂S

“Fast”

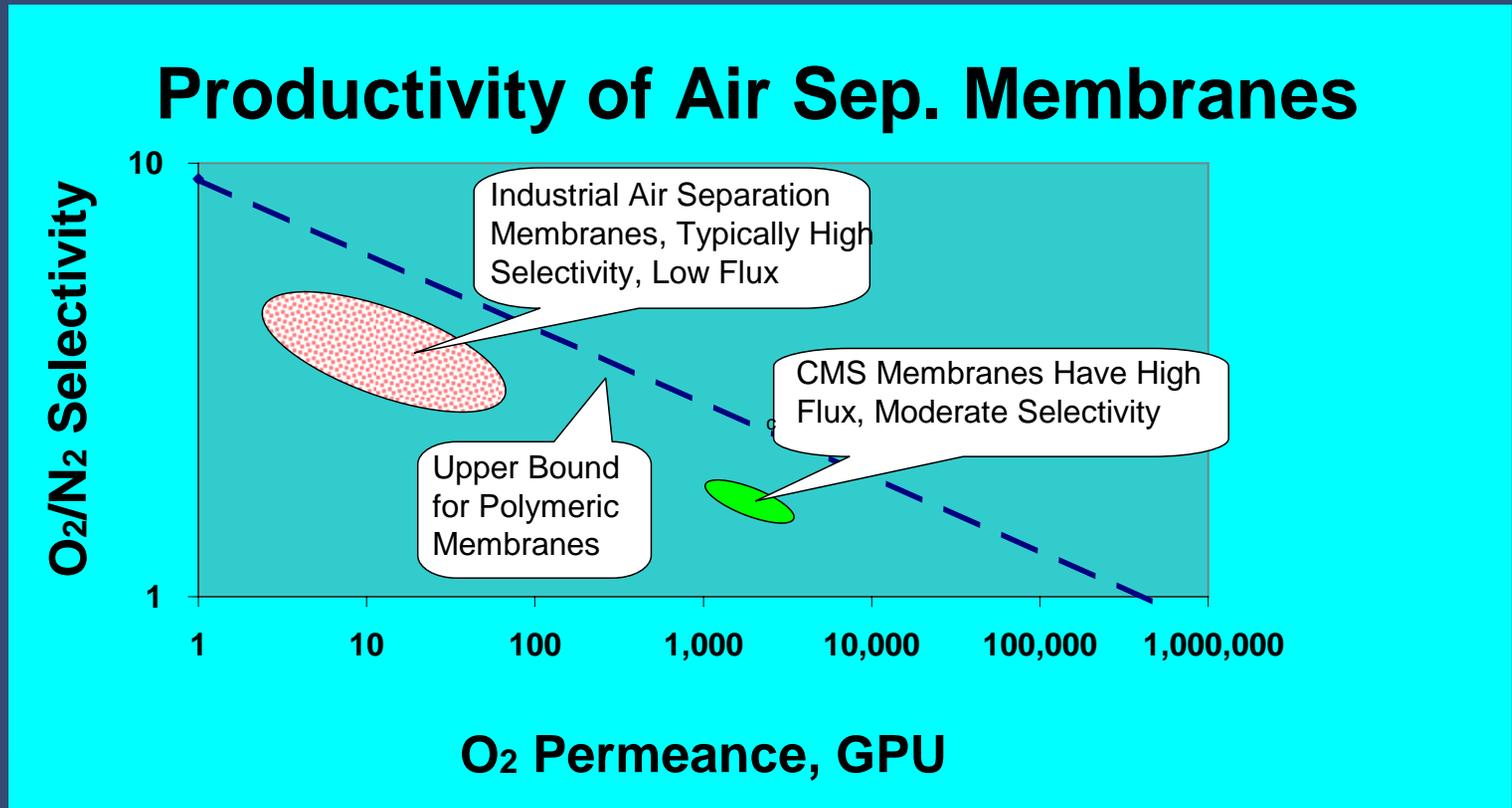
CO₂, O₂

Ar, CO, N₂, CH₄

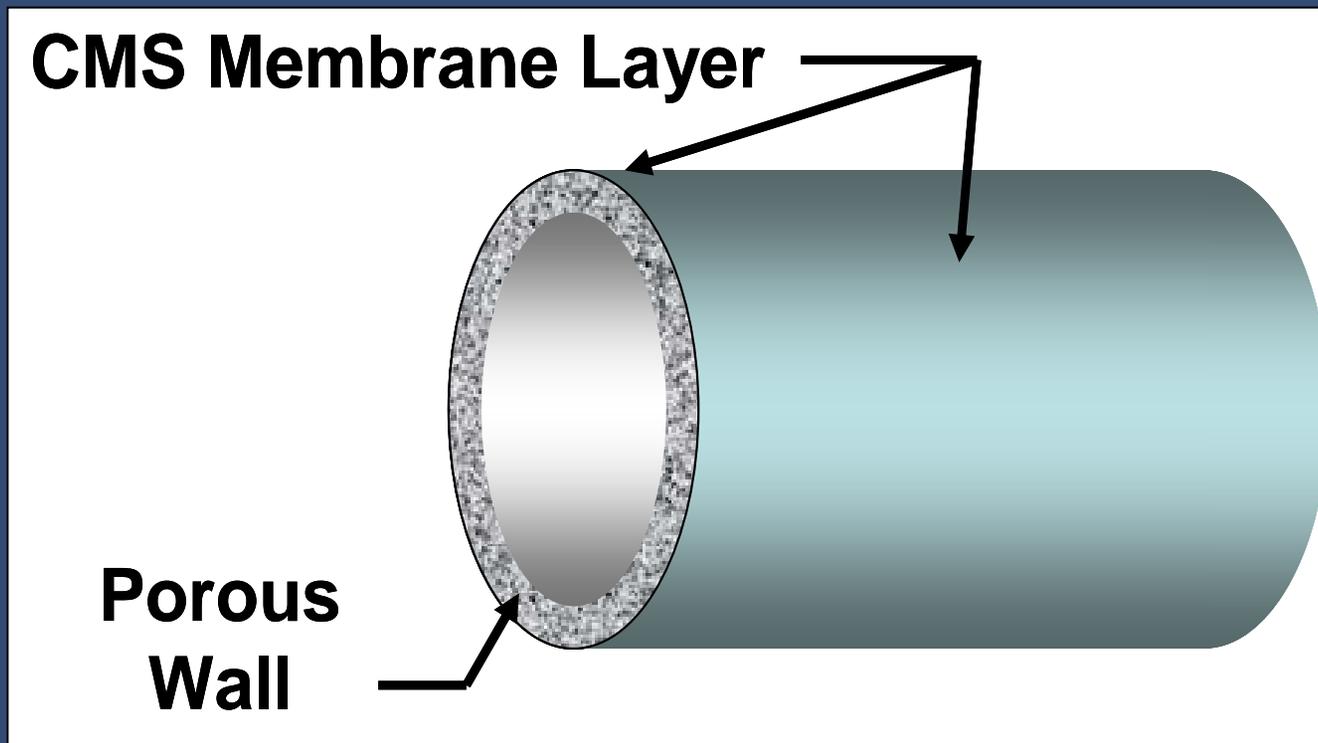
“Slow”

Relative Permeation Rates

Productivity of Polymeric Air Separation Membranes

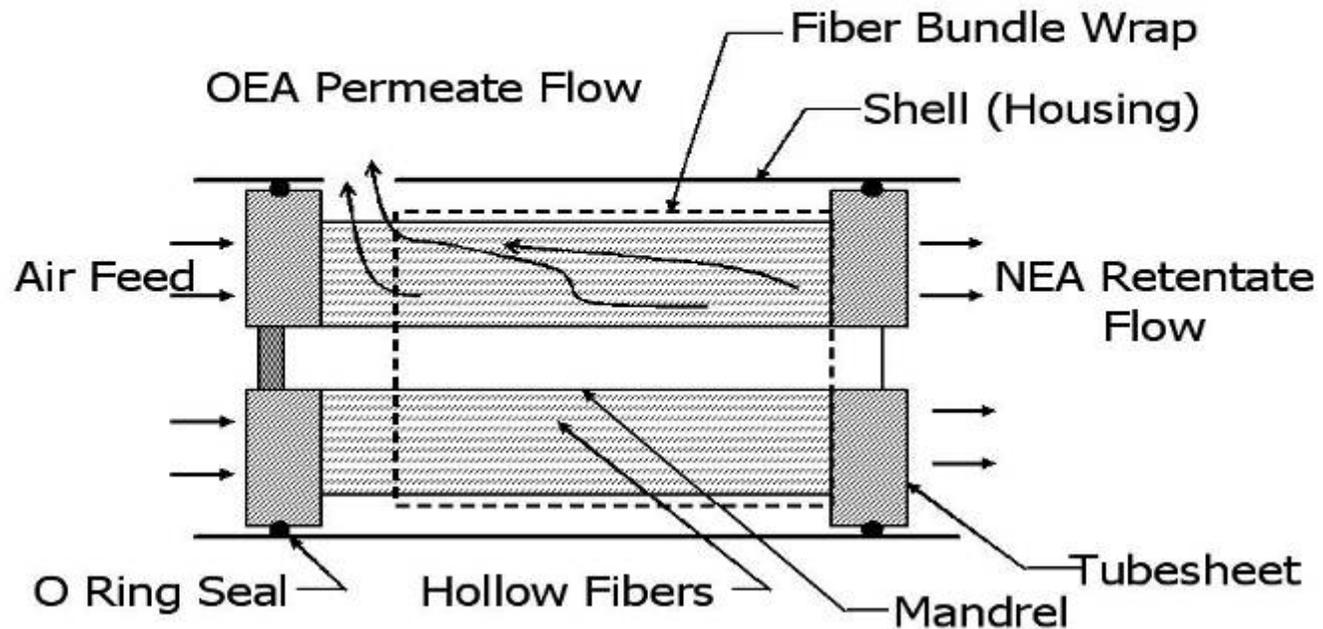


Hollow Fiber Membrane

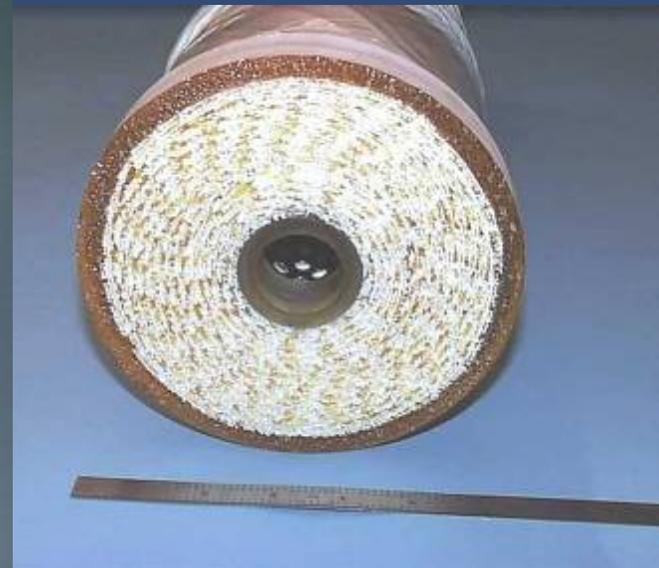


Membrane Cartridge

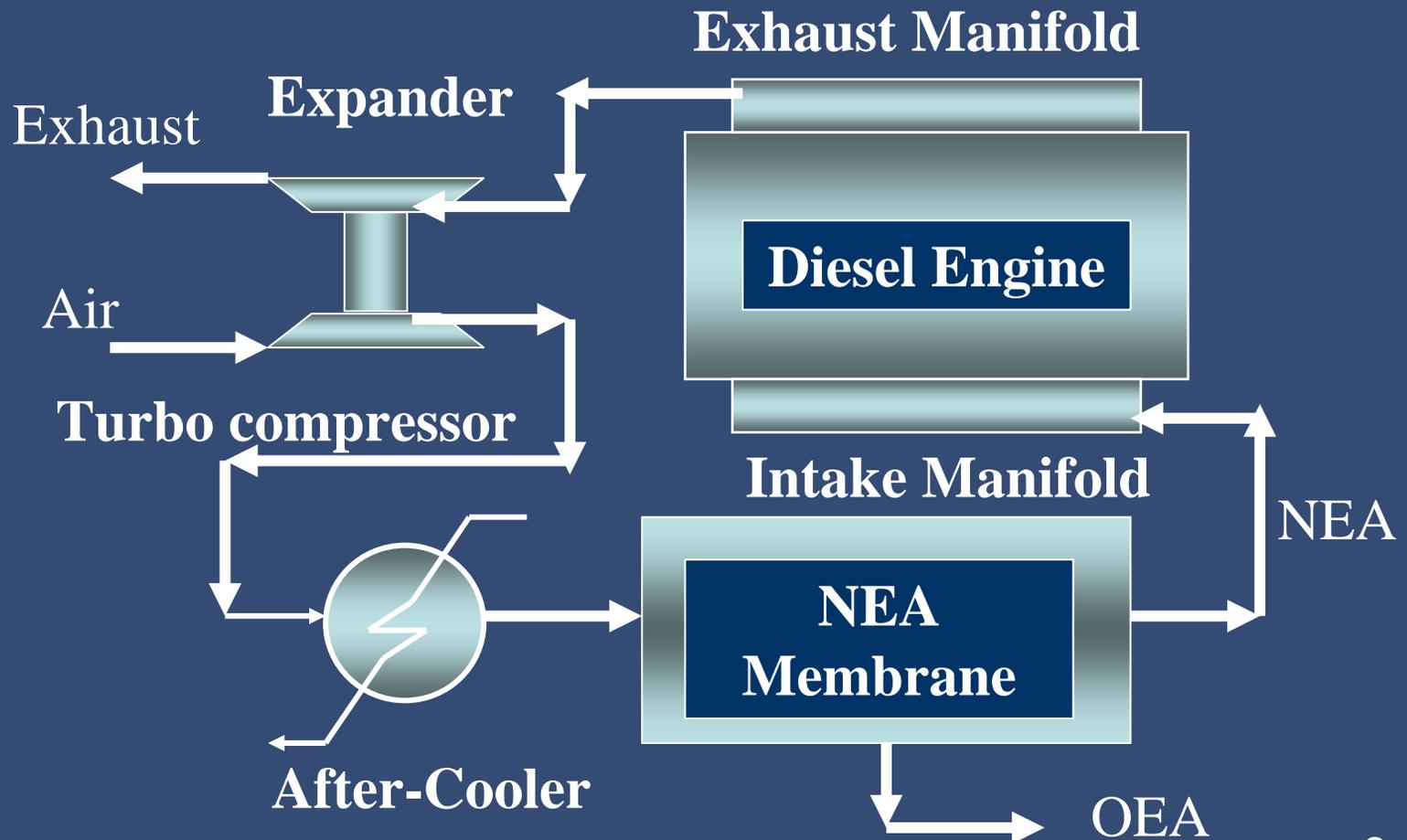
Flow Schematic



CMS Hollow Fiber Membrane Cartridge, 6" dia. x 17"

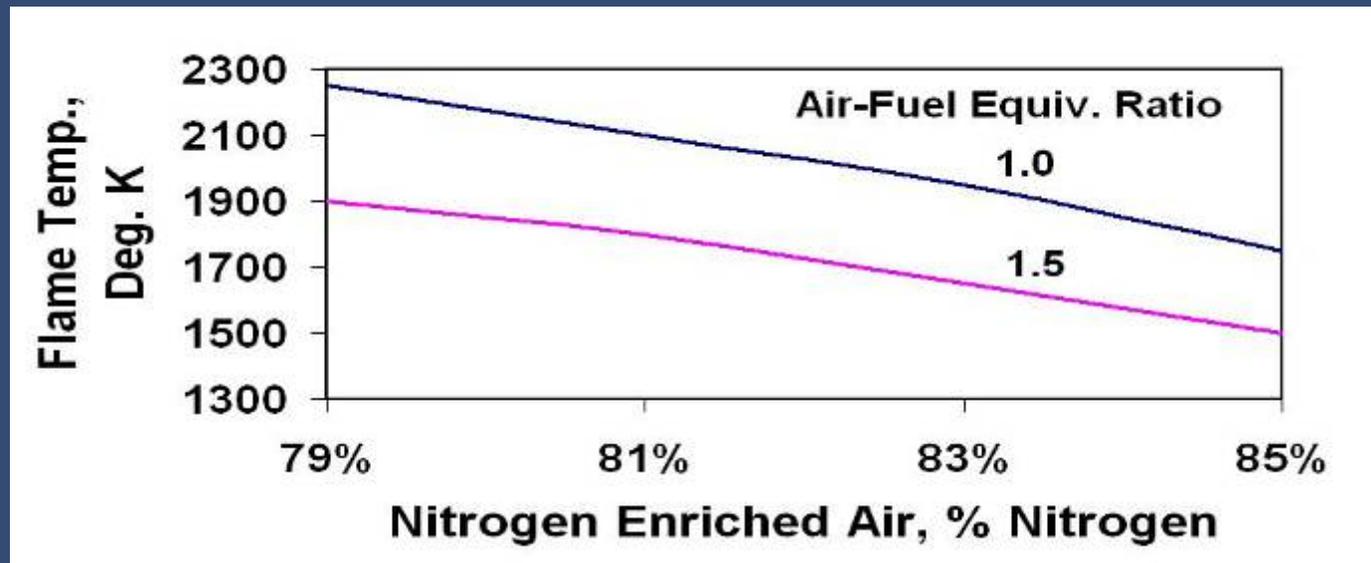


Diesel Engine with NEA Membrane

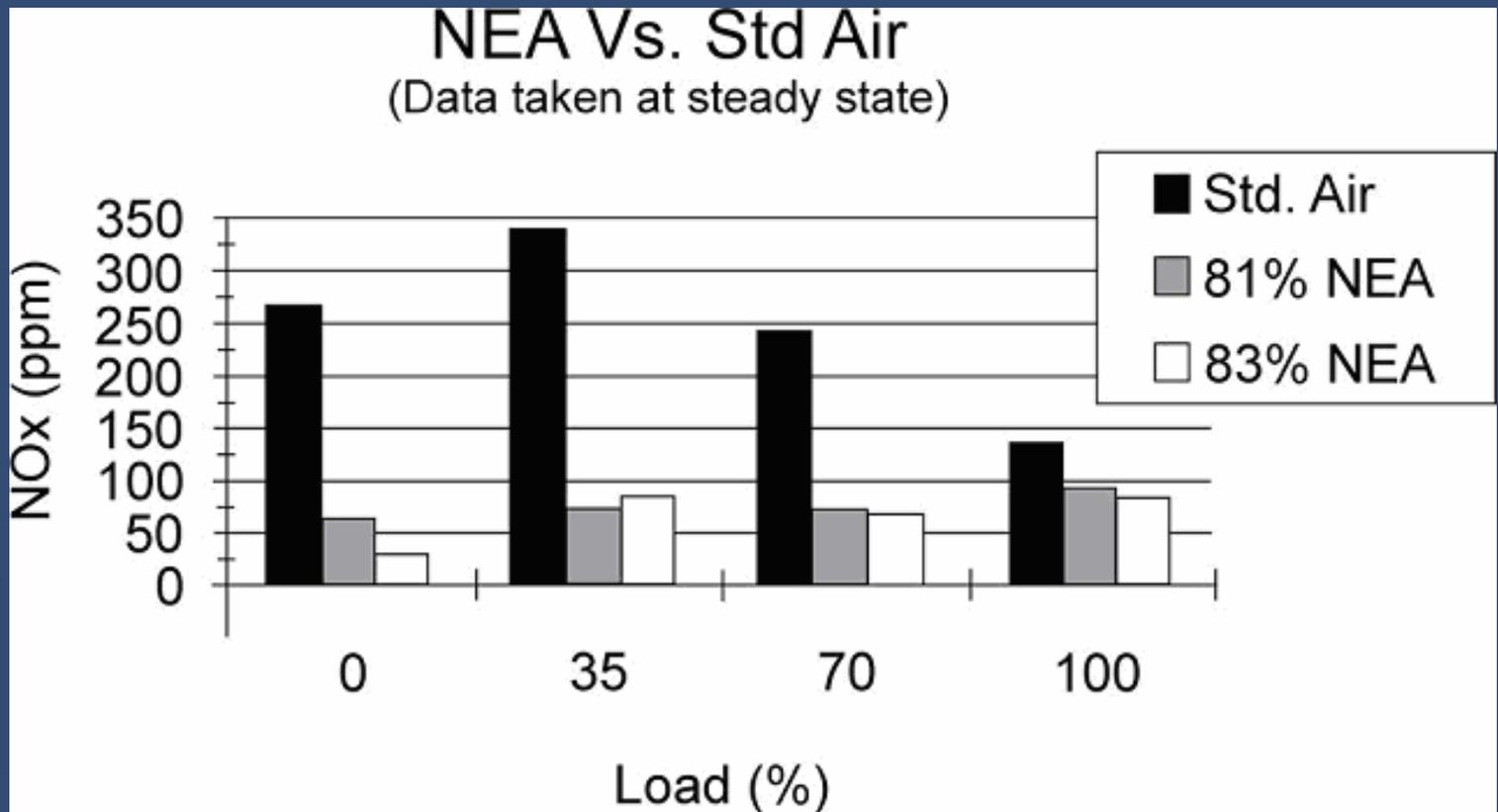


Lower Flame Temperature Favors Lower NO_x Formation

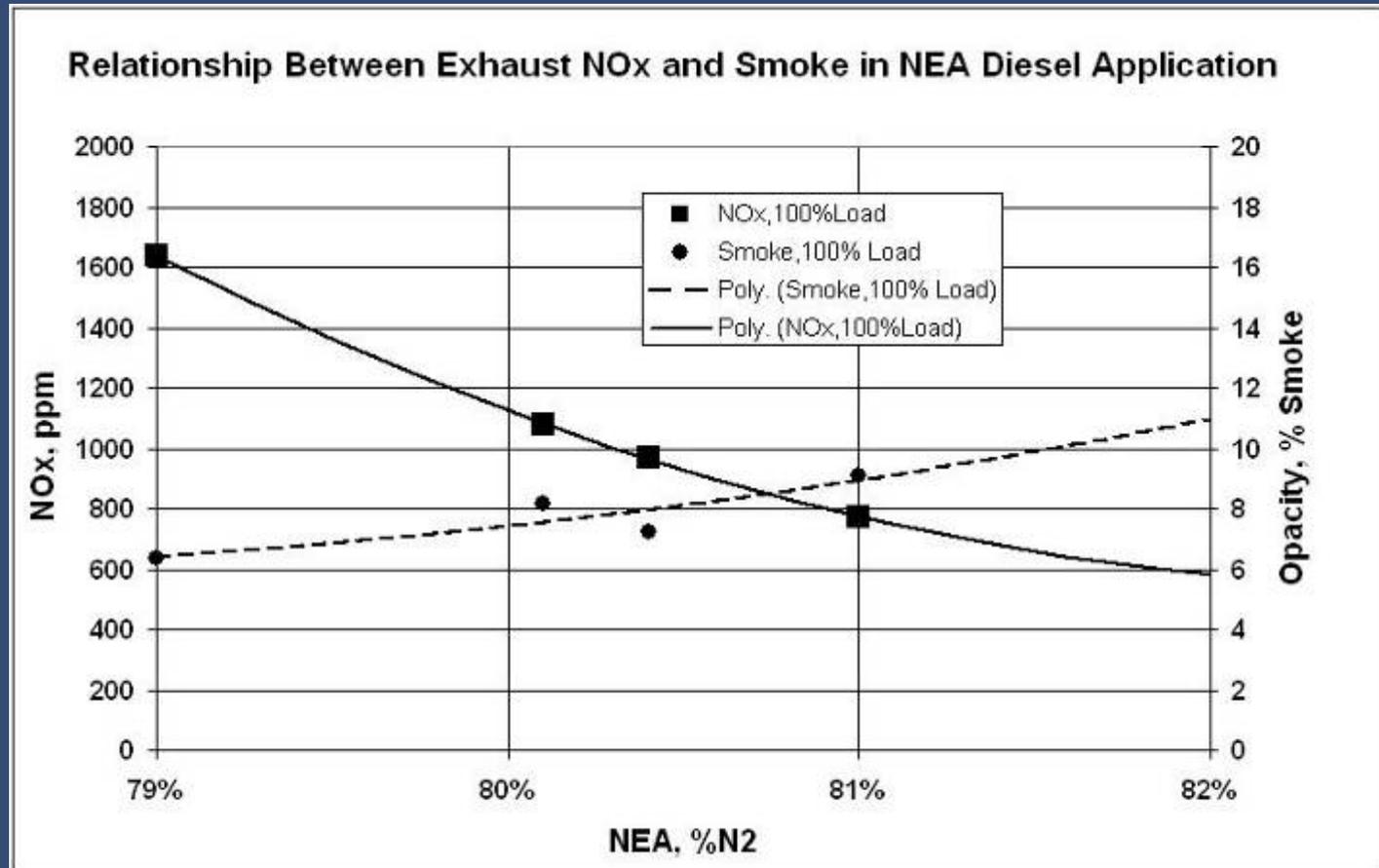
- Influence of NEA and Air-Fuel Ratio on Adiabatic Flame Temperature



NOx for One Cyl. Lab Engine with NEA

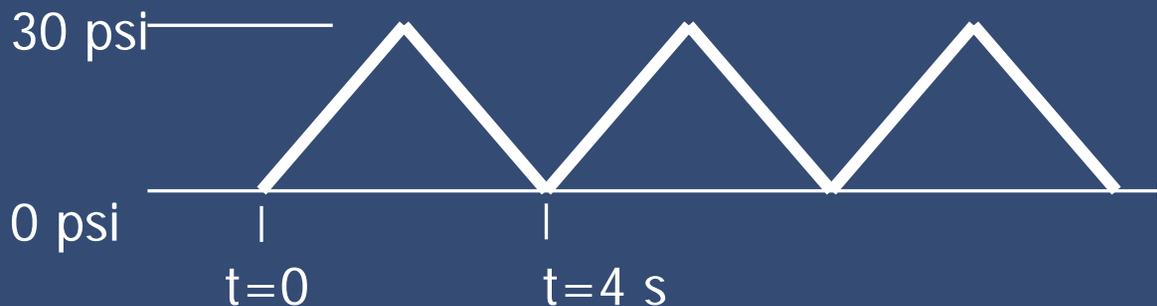


NOx Emissions on L-P Genset



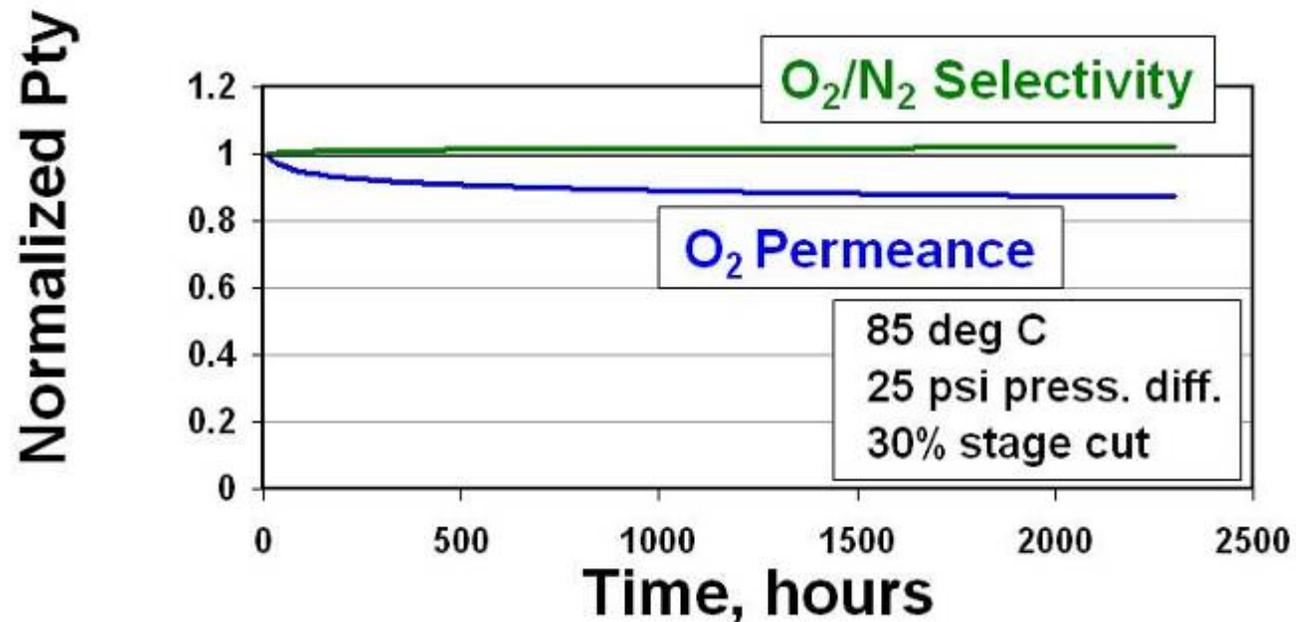
Accelerated Durability Tests

- Durability – Resistance to pressure cycling
 - 0 to 30 psig at extreme temperature of 85 deg C
- Goal – 300,000 cycles at 0 to 30 psi
 - Simulates 435k miles for engine on-highway truck
- Rate – 2 seconds up, 2 seconds down
 - Simulates typical boosting rate in transient loading
- Two weeks to achieve 300,000 cycles
- Ultimately, demonstrated > 1,000,000 cycles to onset of failure

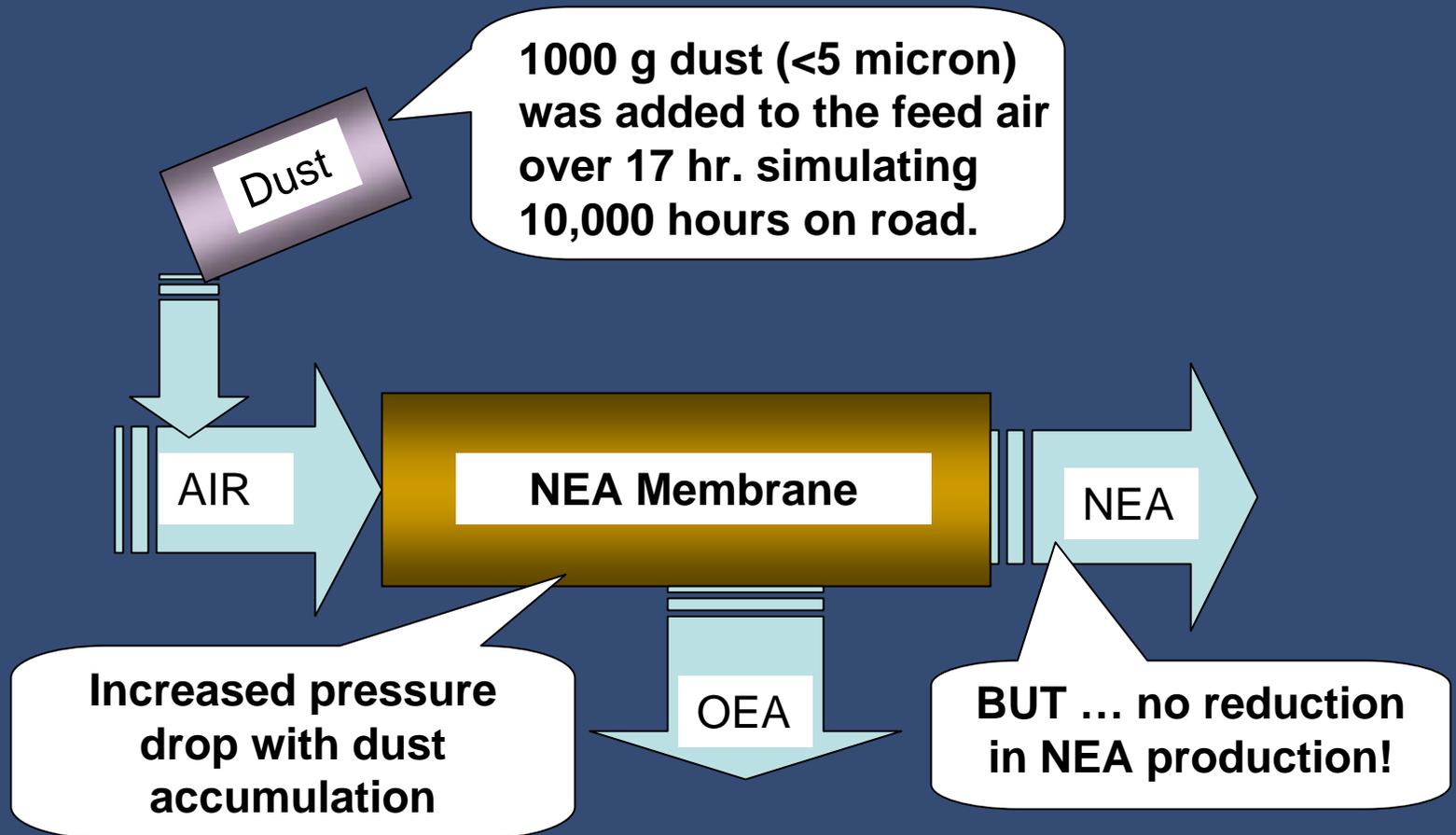


Life at High T – Keeps ON ...

Long-Term NEA Cartridge Performance

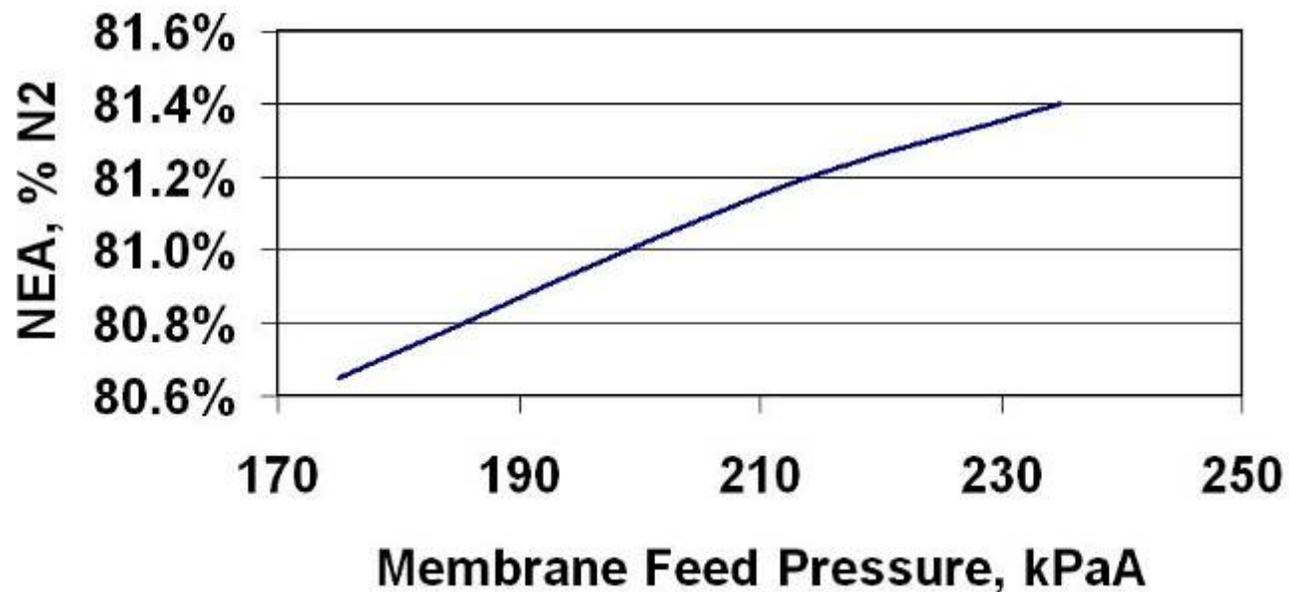


SwRI Accelerated Road Dust Test



Fixed Memb. Area, Variable Boost

Influence of Boost Pressure on NEA Product (typical)

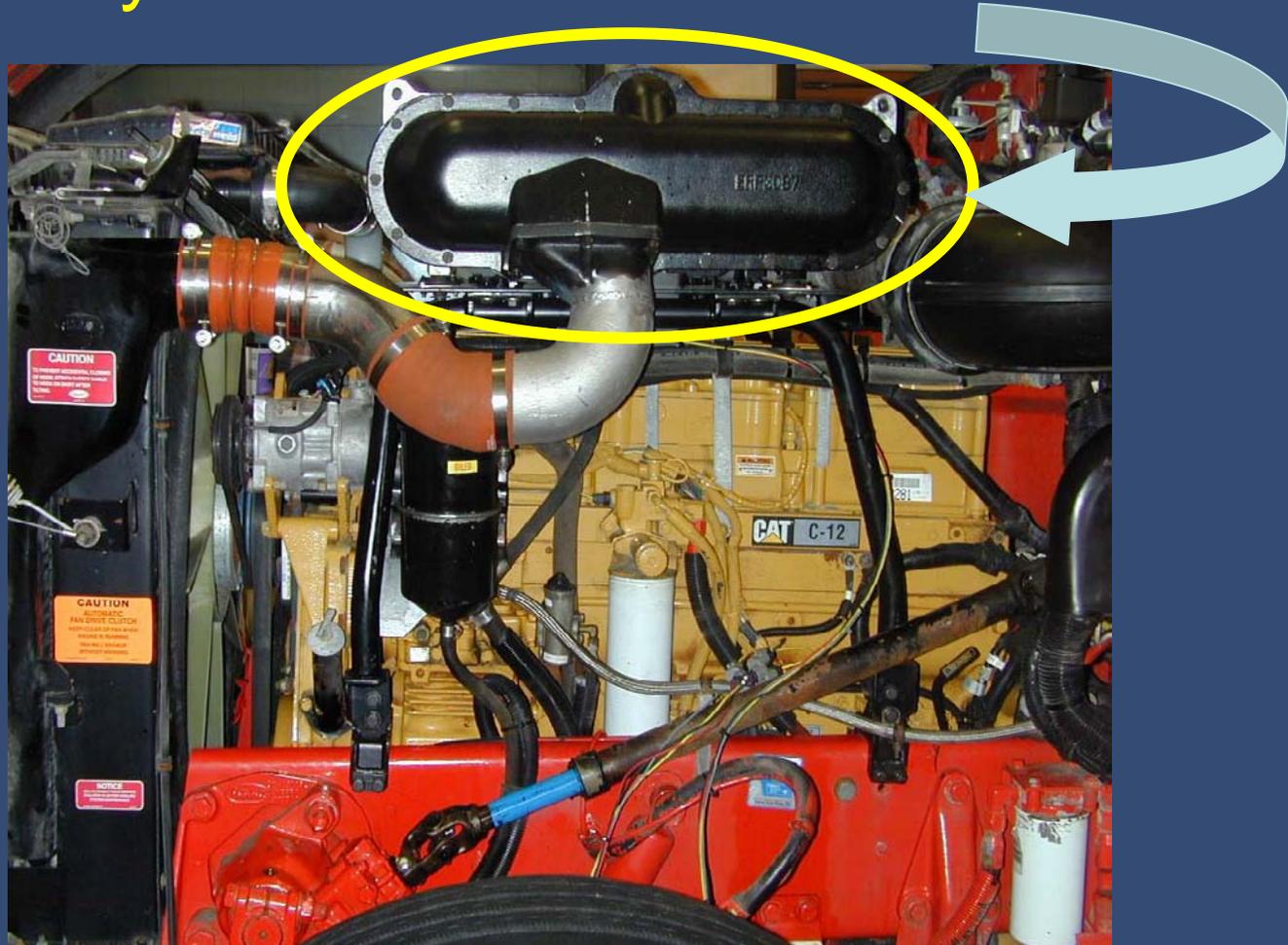


Lab Engine Emissions Tests

Steady State 13 Mode Cycle Results on NEA Modified CAT C-12 Engine

(g/hphr)	2000 6g NOx Production C-12 Engine	C-12 Engine With NEA	2004 EPA Standard
NOx	5.5	2.41	
NOx + HC	5.6	2.50	2.50
Particulate	0.04	0.097	0.100

Reality - Membranes Under the Hood!

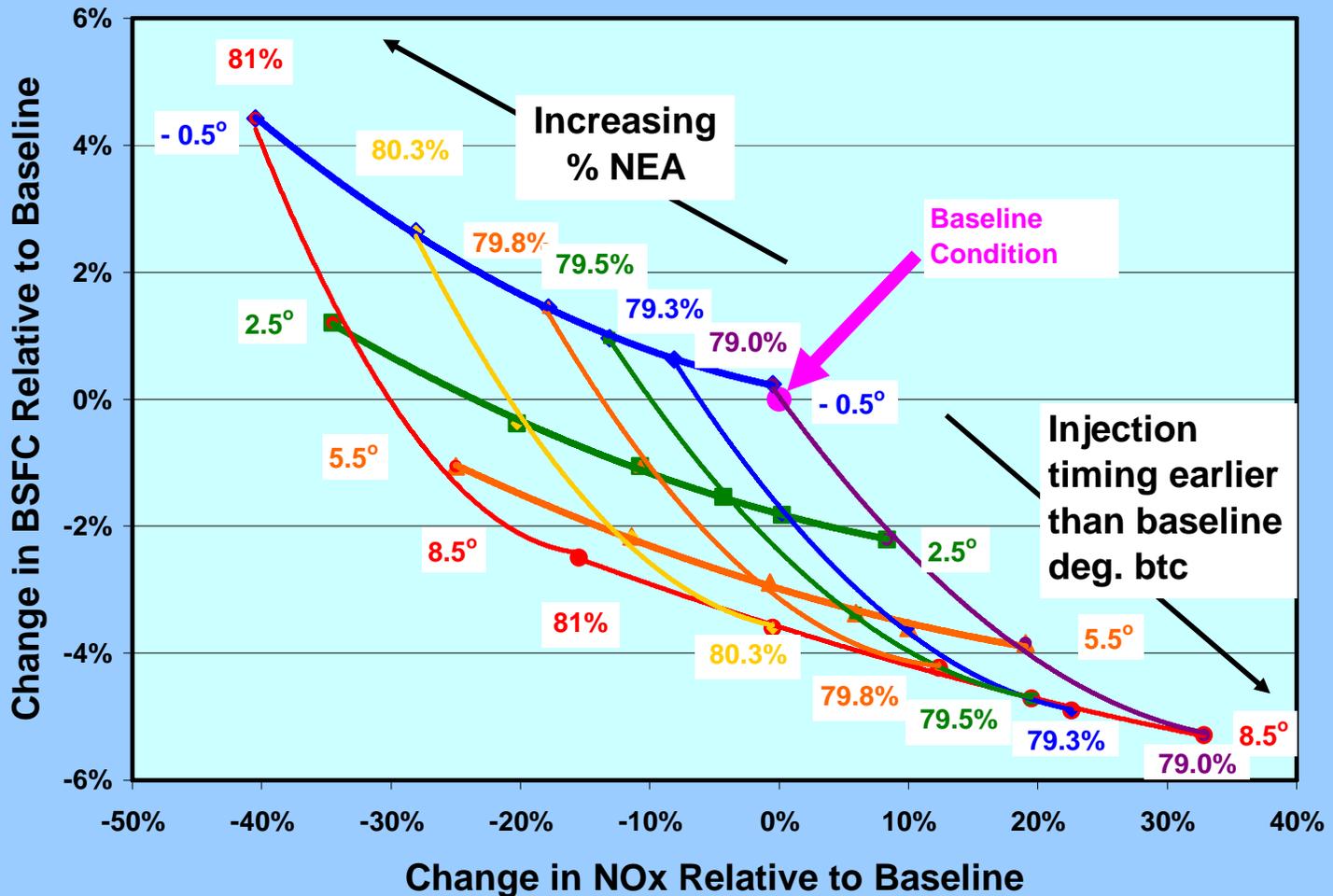


Field Durability Test Program

- Five Class 8 Highway Trucks
- Outfitted with NEA Membranes
- Exceeded total of **1 million miles** on the road
- No evidence of Membrane Fouling
 - All Five Over 150,000 miles
 - One over 270,000 miles

Typical Performance

Sensitivity of BSFC and NOx to Timing and % NEA



Status

- Commercialization Phase
 - Membrane Supply
 - NOx Reduction Certification by EPA
- OEM Engine Manufacturers
 - Truck and Off-Road
 - Generators and stationary power
 - Locomotive
 - Marine
- Distributors
 - Retrofit of existing diesel engines
 - Compliance with local or regional emission regulations

