Future Energy Conversion Technologies for Heavy Vehicles -- Prospects and Promise

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of the Combustion Institute
Session on The Future of Combustion in Transportation
Oakland, CA
March 26, 2001

OHVT Mission

To conduct, in collaboration with our heavy vehicle industry partners and their suppliers, a customer-focused national program to research and develop technologies that will enable trucks and other heavy vehicles to be more energy efficient and able to use alternative fuels while simultaneously reducing emissions.

Outline

- The Transportation Energy Situation
- Creating Transportation Options
- Alternatives to Carbon-Based Fuels
- The Future of Combustion in Transportation
- The Outlook on Combustion Engine Emissions
- Diesel Engine Emissions Control Strategy
- Diesel versus Gasoline Emissions
- Summary

U.S. Highway Fuel Consumption

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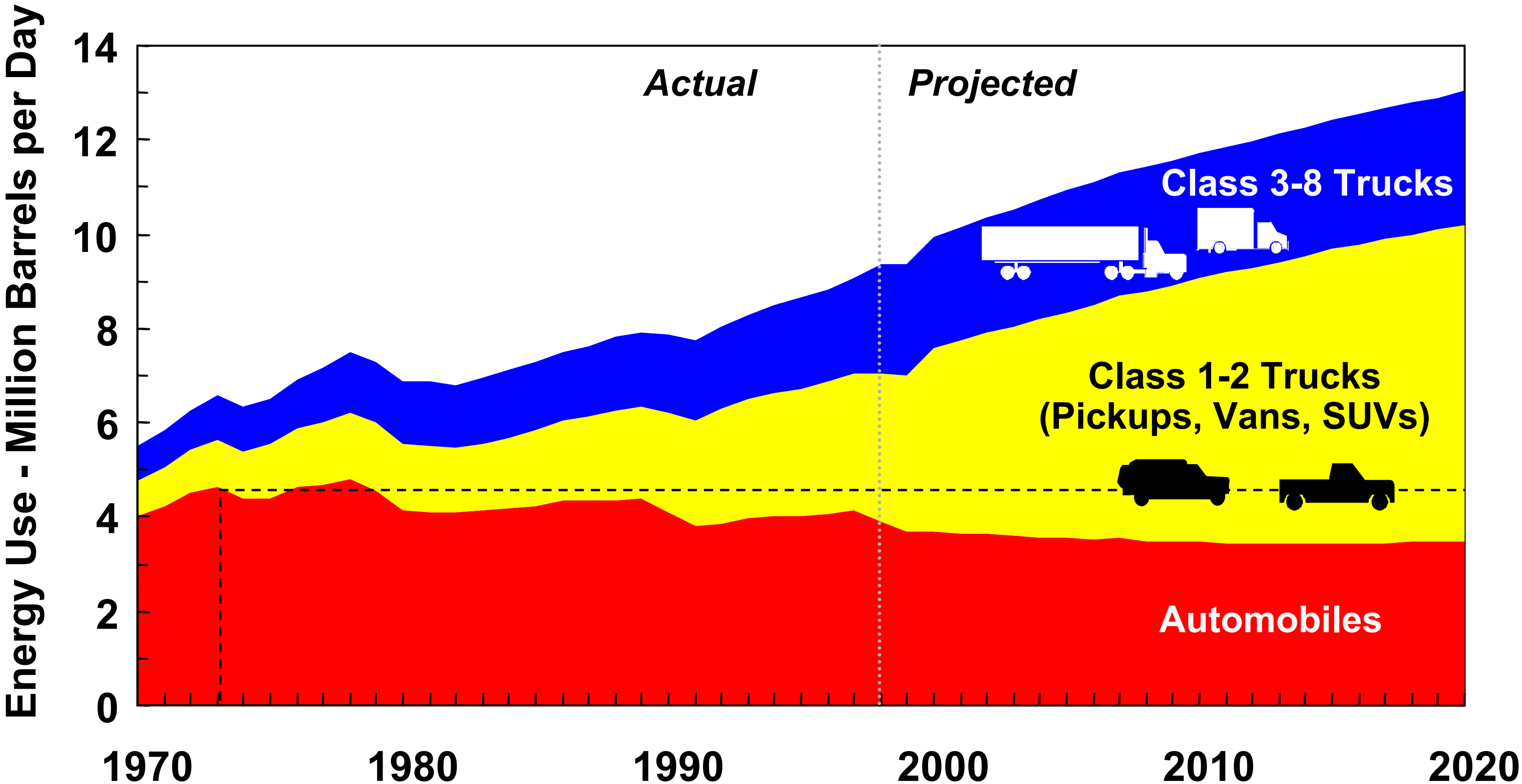
Since The 1973 Oil Embargo All Of The Increase Has Been Due To Trucks



Sources: *EIA Annual Energy Outlook 2000*, DOE/EIA-0383(2000), December 1999
Transportation Energy Data Book: Edition 20, DOE/ORNL-6959, October 2000

U.S. Energy Situation

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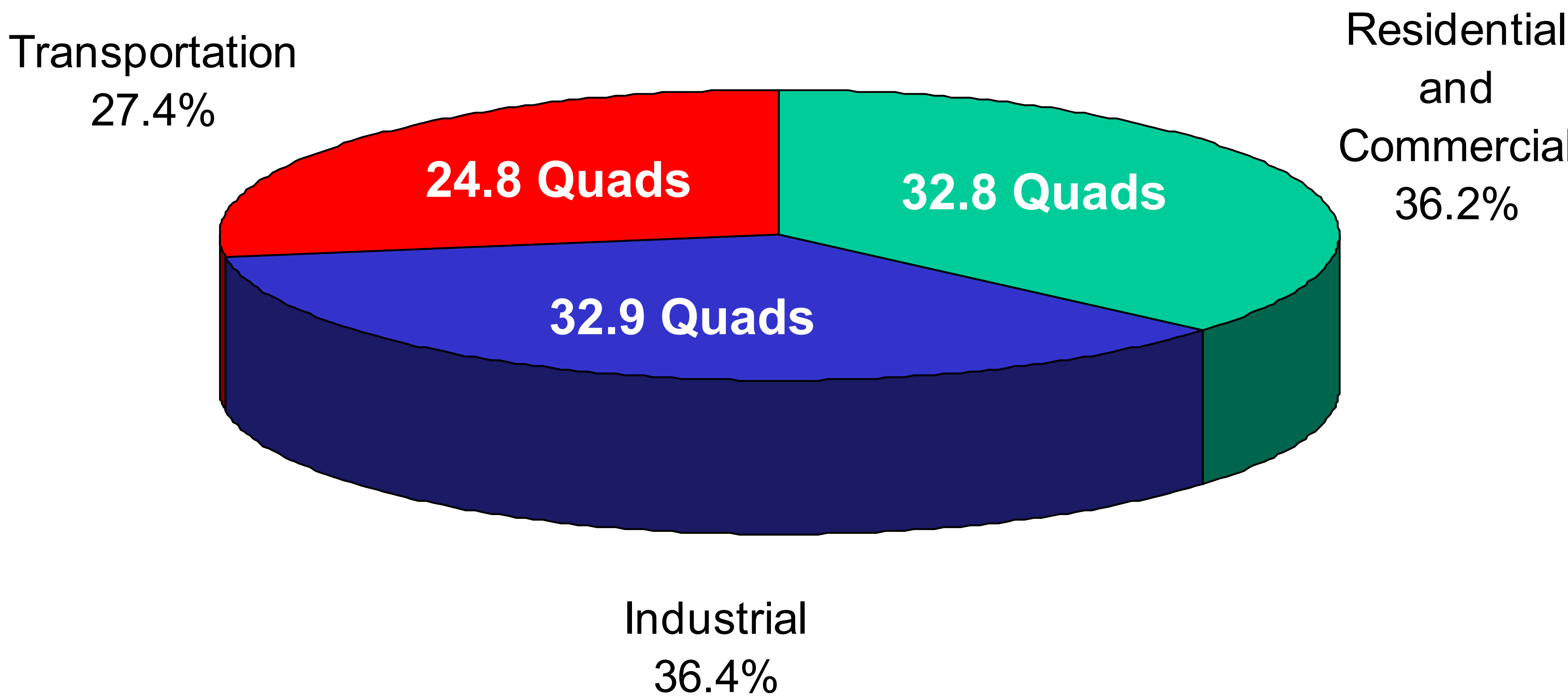
Primary Energy Consumption by End-Use Sector, 1997



Source: DOE/EIA Monthly Energy Review; July 1998

1 Quad = 1 Quadrillion BTUs = 1 x 10^{15} BTUs ≅ 1 x 10^{18} Joules

The Transportation Sector Is Almost Totally Dependent on Liquid Carbon-Based Fuels

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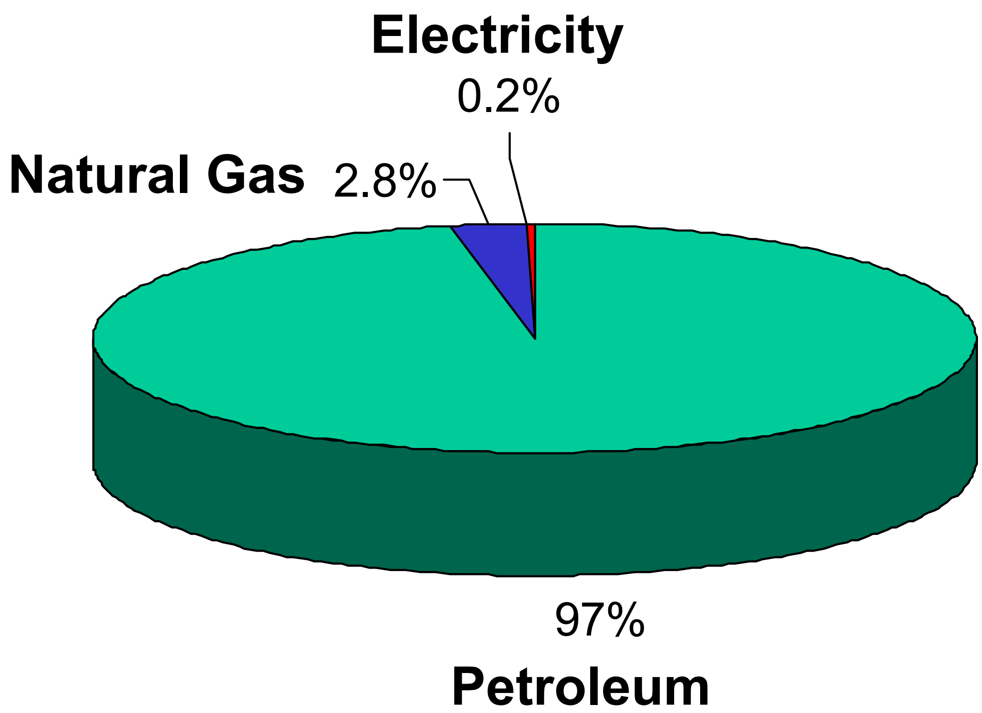
Transportation Energy Consumption, 1997



Source: DOE/EIA Monthly Energy Review; July 1998

Creating Transportation Options for the 21st Century

History of "Promising" Alternatives

- **1960s**
  - Steam (Rankine cycle) engines
- **1970s**
  - Gas turbines
  - Stirling engines
- **1980s**
  - Adiabatic engines
  - Alternative fuels
- **1990s**
  - Hybrids
  - Fuel cells

Transportation Energy Conversion Technology R&D

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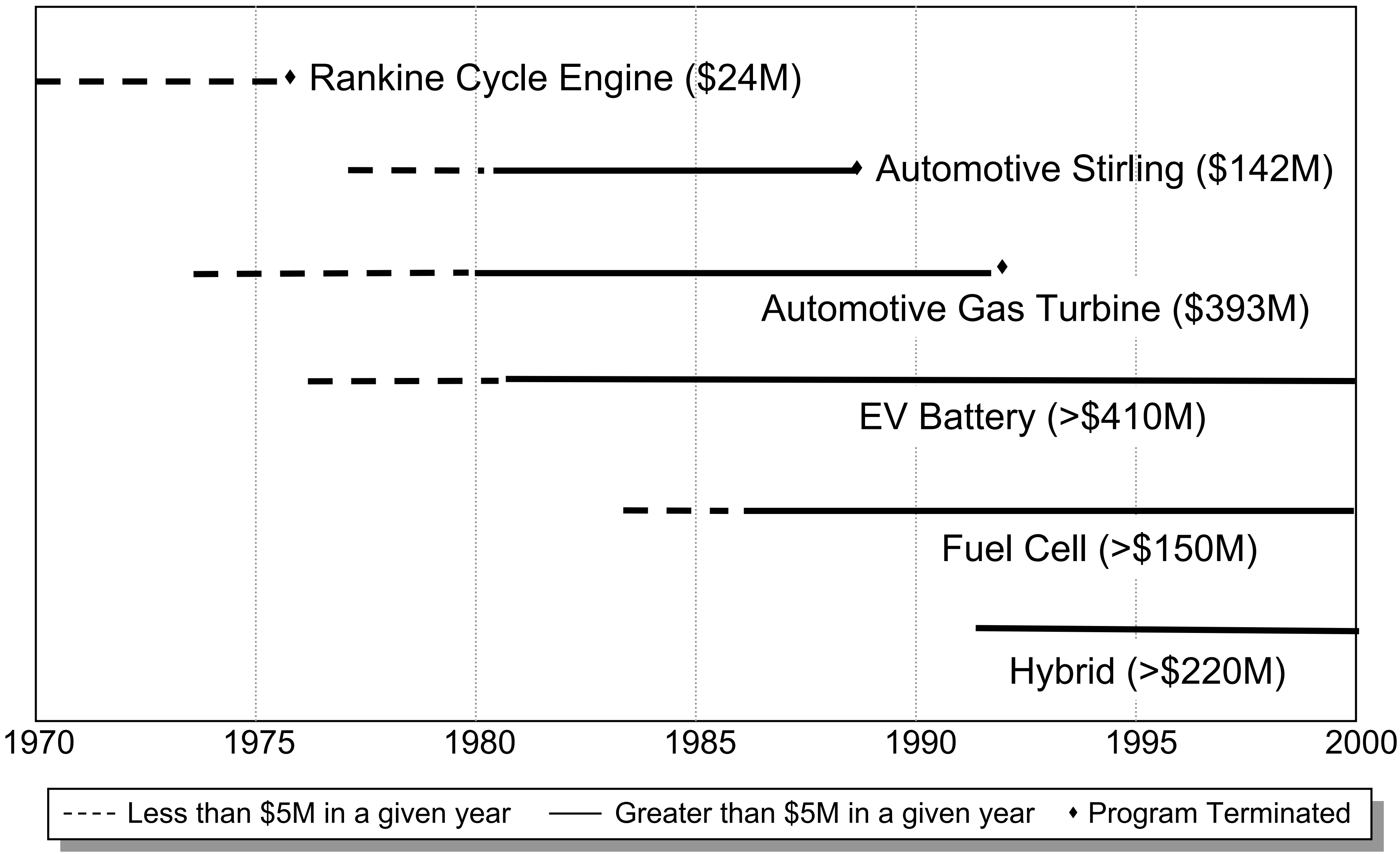

Selected Technologies for Improved Fuel Economy

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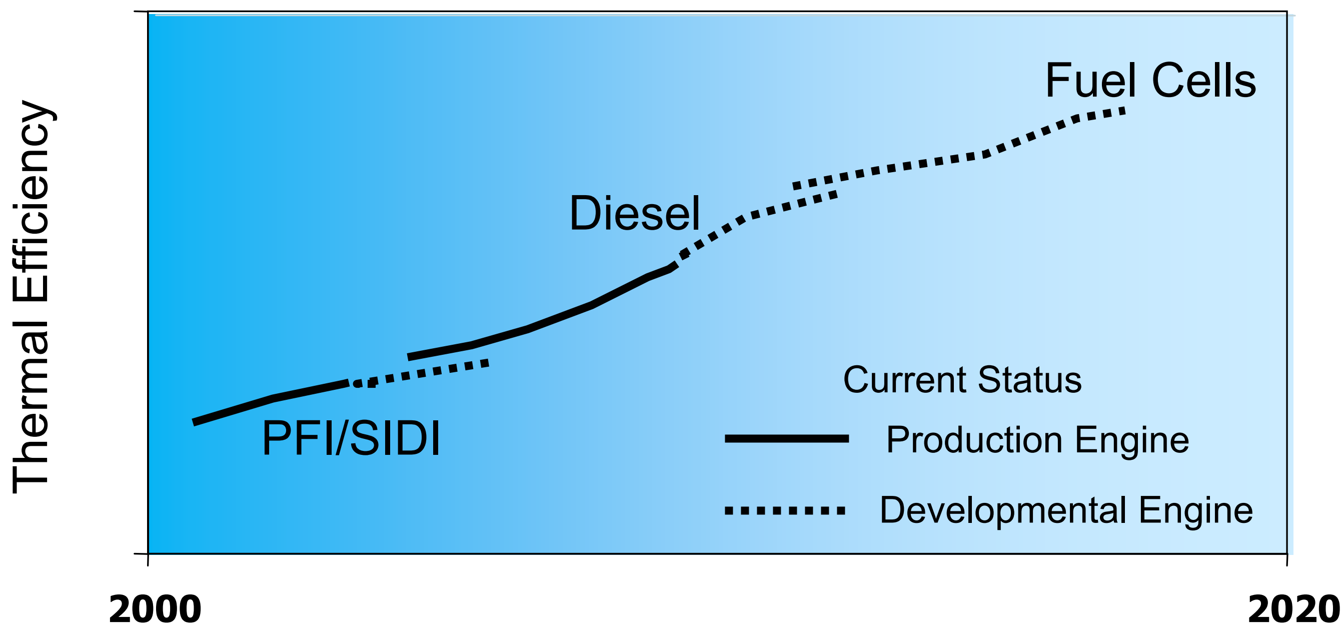
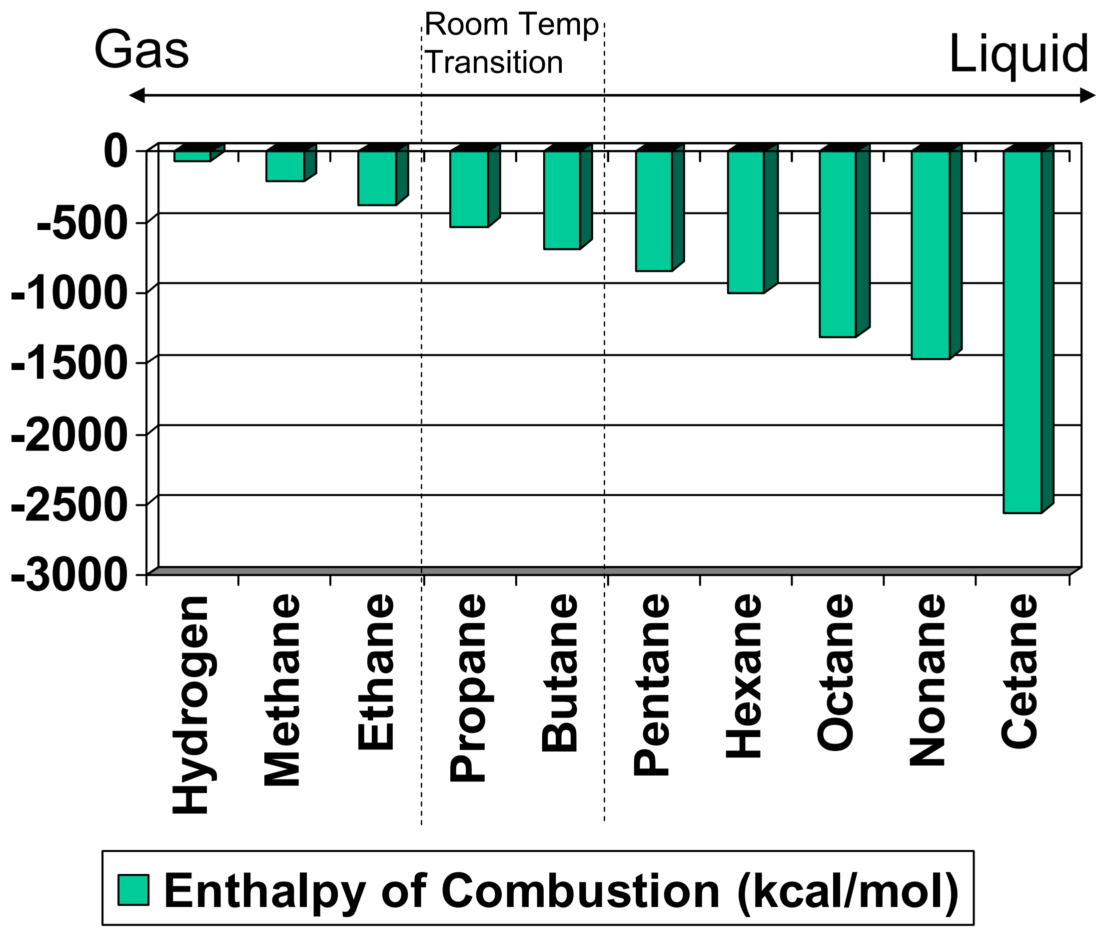


Contributing Technologies

- Lightweight materials
- Reformulated fuels
- Hybridization
- Vehicle System Improvements

Alternatives to Carbon-based Fuels

As a chemical storage system, we have no practical substitute for the C-C bond.



Energy Density of Fuels

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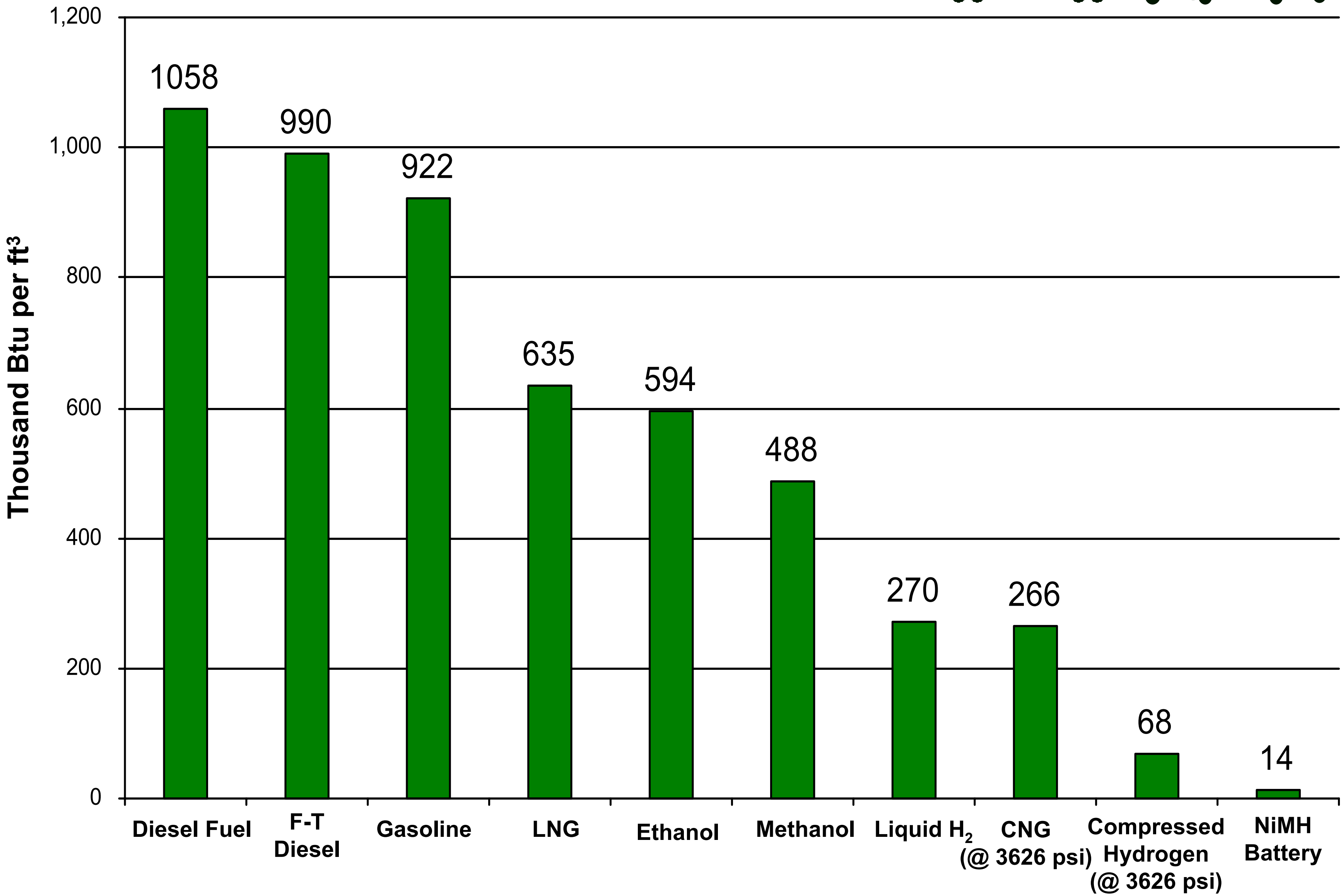

Comparison of Energy Conversion Efficiencies

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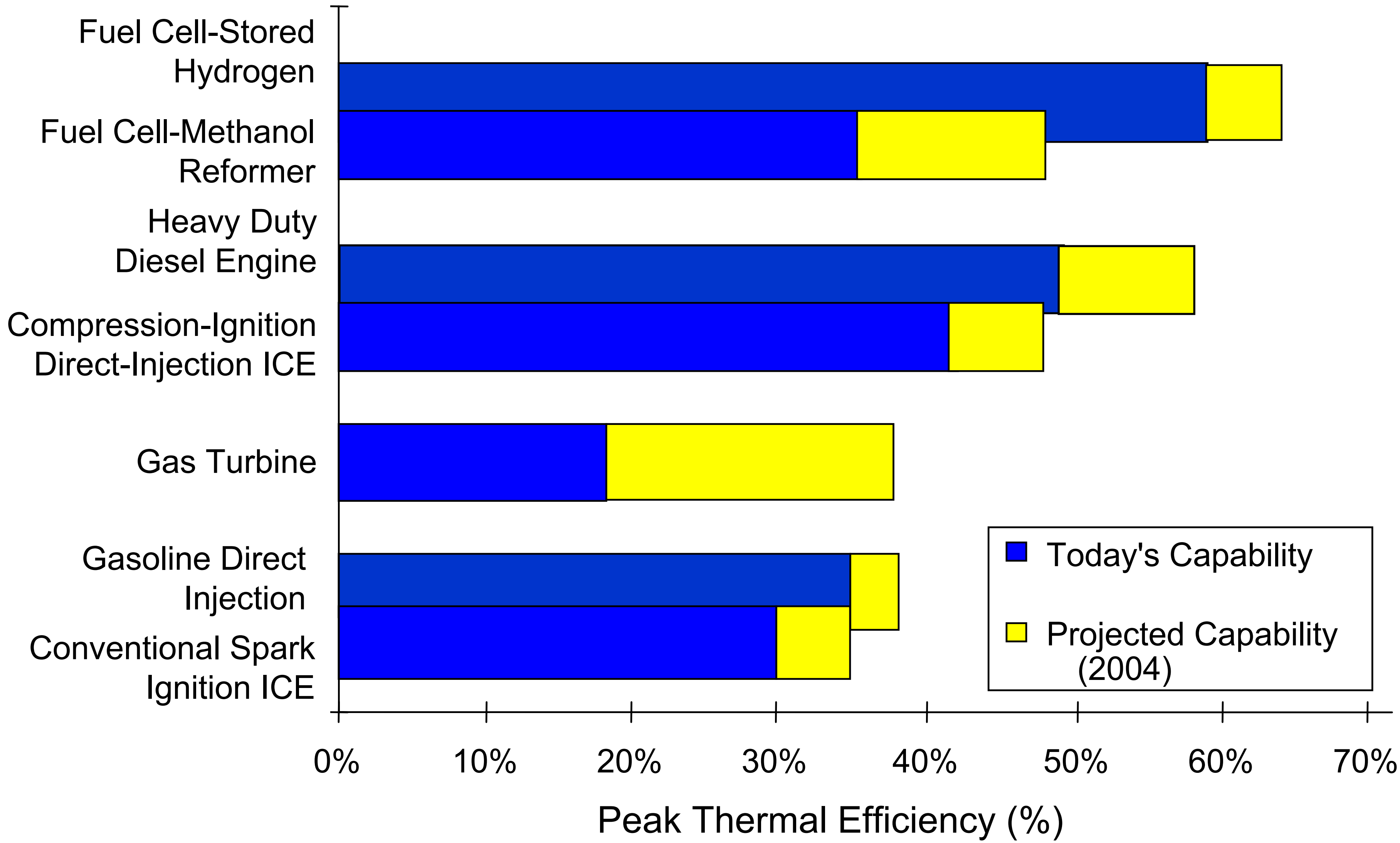

Vehicle Range Limitation - Challenge To Be Overcome By Alternatives

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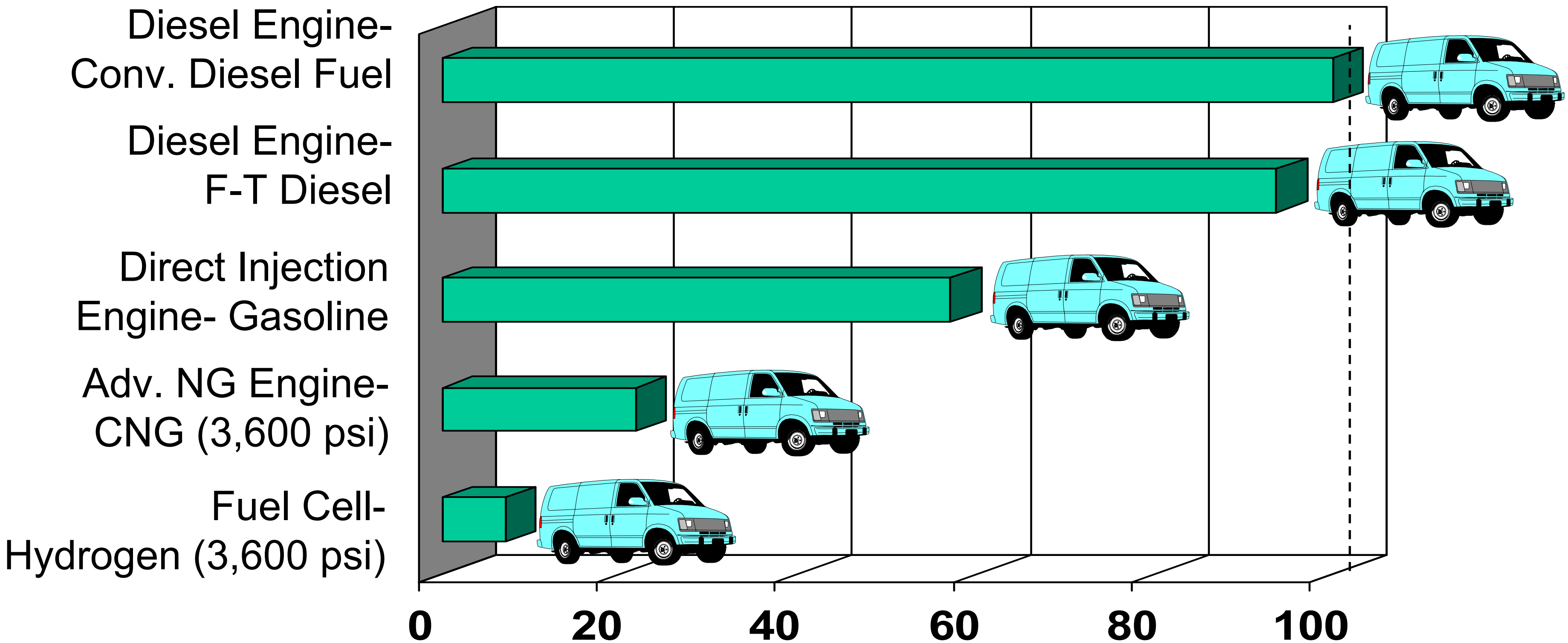

Comparison of Miles Driven (Same Volume of On-Board Fuel)

Combustion Engines Are Still the Most Viable for Future Heavy Vehicles - - Some Challenges

- Understanding the combustion characteristics of new fuels, e.g., 100 percent paraffinic fuels such as Fischer-Tropsch diesel or fuel blends
- Understanding how to achieve or control homogeneous charge in compression ignition engines
- Understanding the benefits of multiple injection and real-time combustion control
- Understanding the fundamentals of exhaust gas recirculation (EGR) and emissions
- Understanding the effects of variable valve timing and engine boosting technologies on combustion and emissions

Heavy-Duty Diesel Engine Progress

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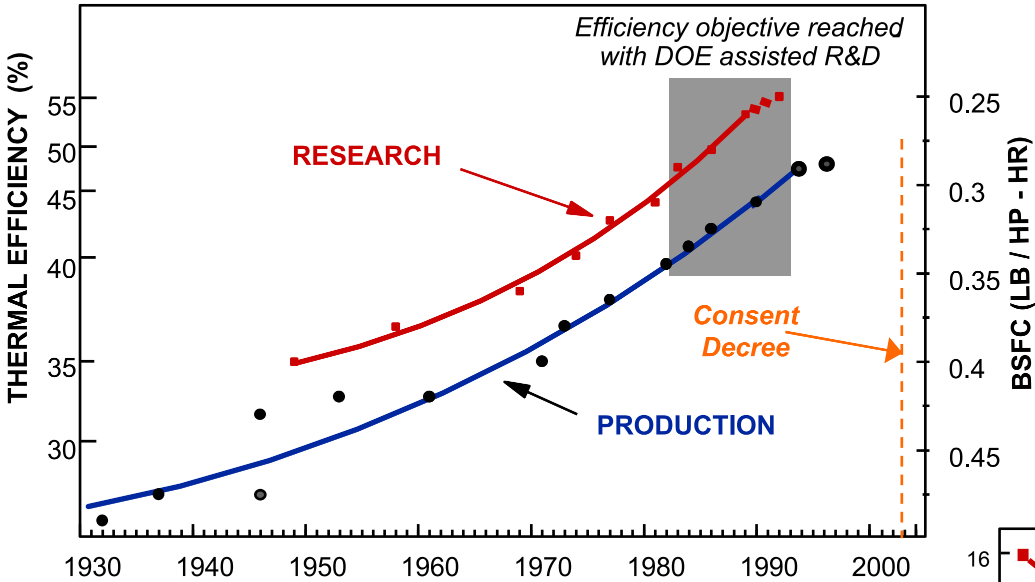
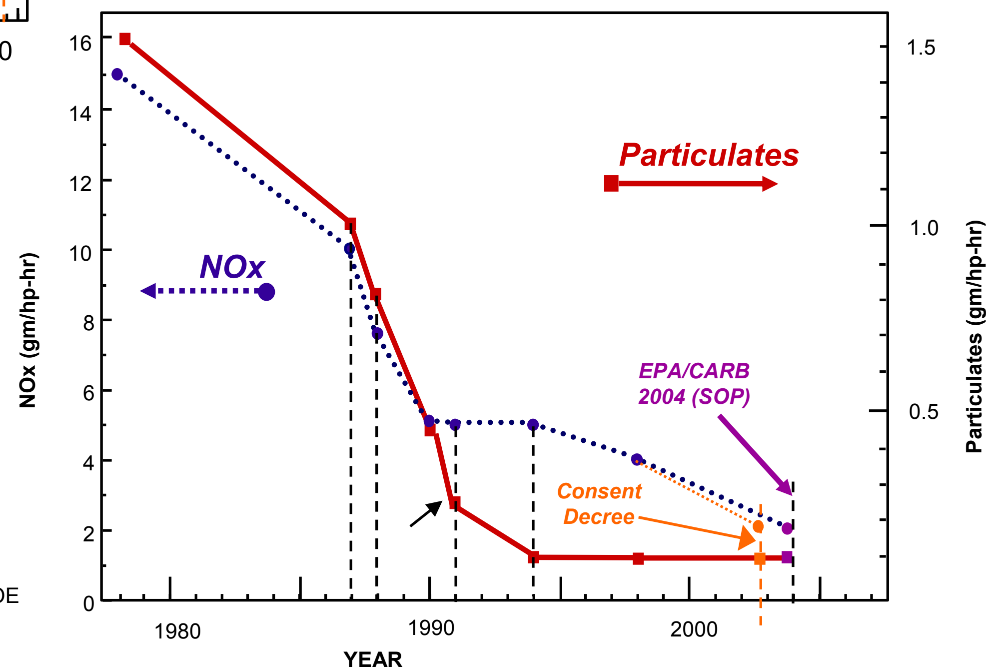
Increasing Efficiency



Source: Caterpillar

Decreasing Emissions



Source: Cummins, modified by DOE

Outlook on Emissions from Combustion Engines for the 21st Century

Transportation and Urban Air Quality

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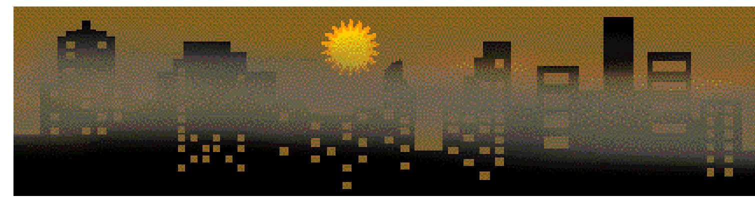
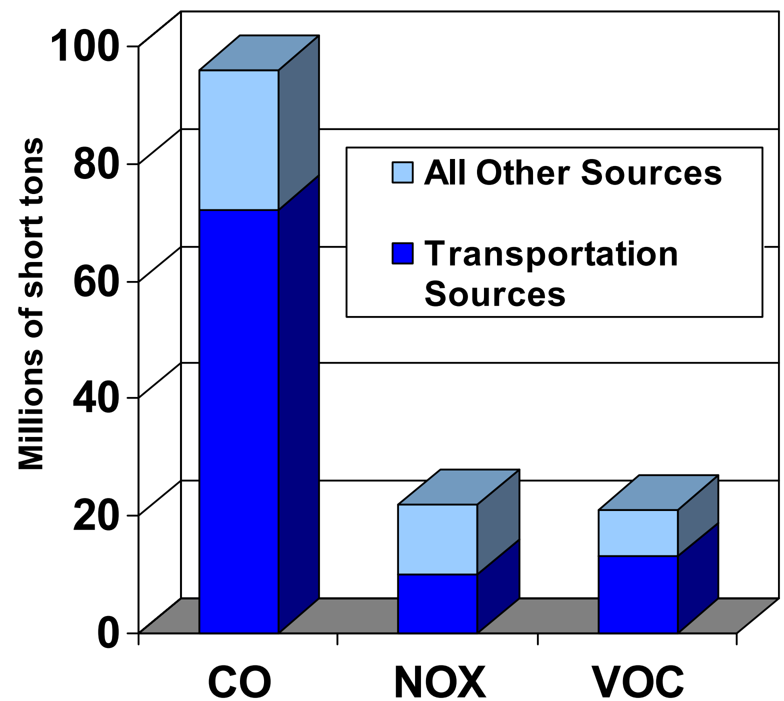
Congestion and Criteria Pollutant Emissions Remain National Concerns, Especially In Urban Areas

- Population and miles traveled continue to increase resulting in increasing congestion and air pollution
- As a result, over 100 million people live in areas not meeting National Ambient Air Quality Standards (EPA, Oct. 1995)





EPA Emissions Standards

- **Tier 2 Regulations for Light-Duty Vehicles (LDVs)**:
  - 0.07 g/mi NOx and 0.01 g/mi PM; represents 77 to 95% reduction from Tier 1 levels
  - Includes all LDVs under 10,000 lbs
  - Phased in 2004-2008
- **Heavy-Duty Diesel Engine Regulations:**
  - 0.2 g/bhp-hr NOx and 0.01 g/bhp-hr PM; represents about 90% reduction from 2004 regs
  - Phased in 2007-2010
- Heavy-duty regulations include ultra-low sulfur diesel fuel

Diesel Cycle Engine Emissions Control Strategy

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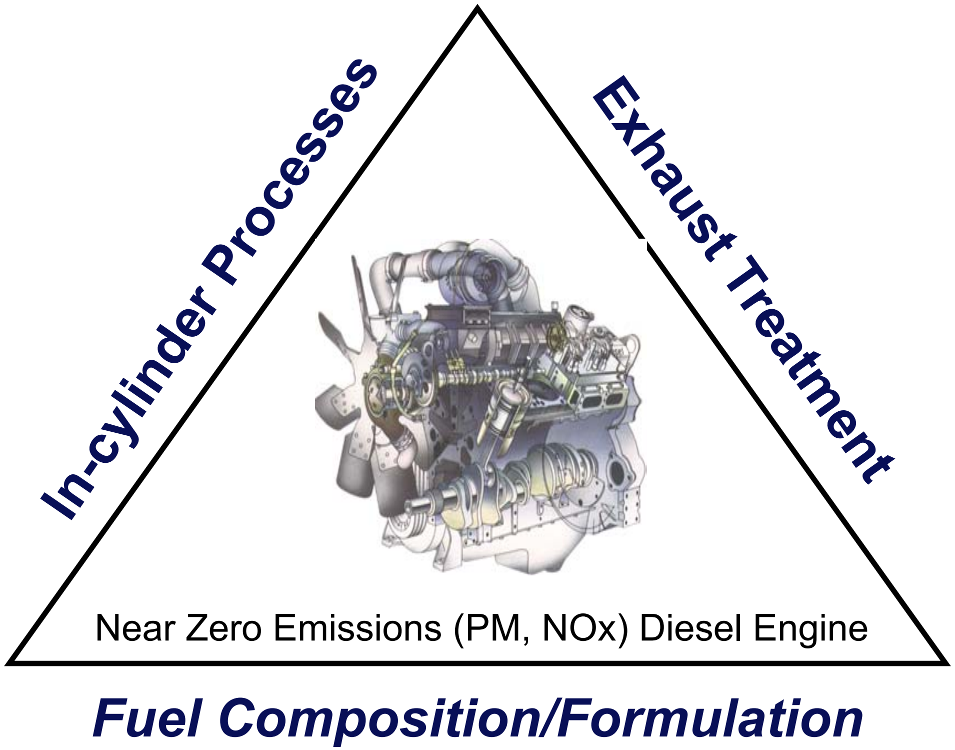

Three-pronged systems approach appears necessary to meet ***very low emissions without sacrificing engine efficiency***

Outlook on Mobile Emissions

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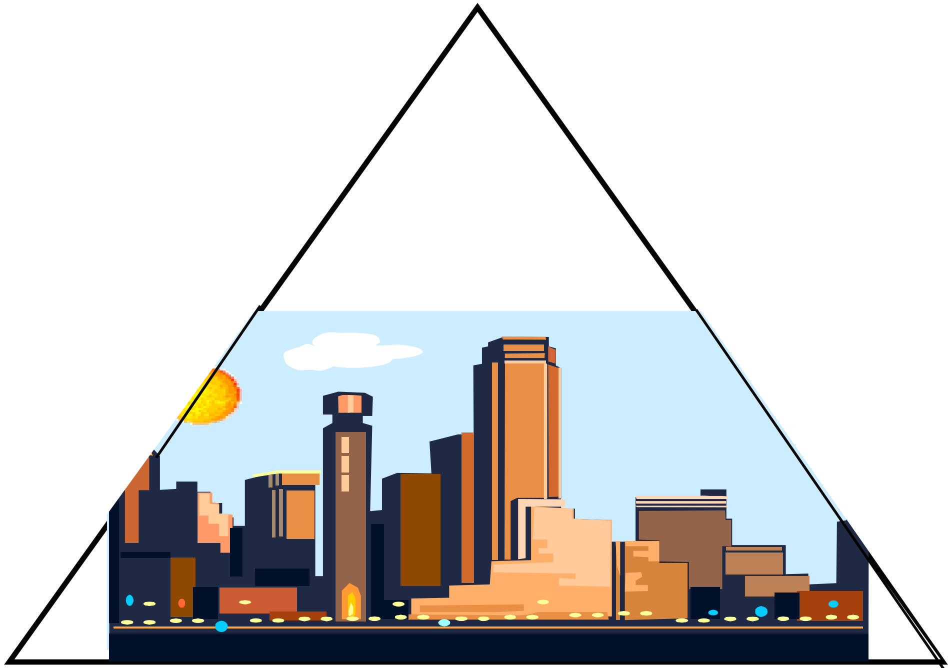
Environmental Groups
(UCS, NRDC, etc.)



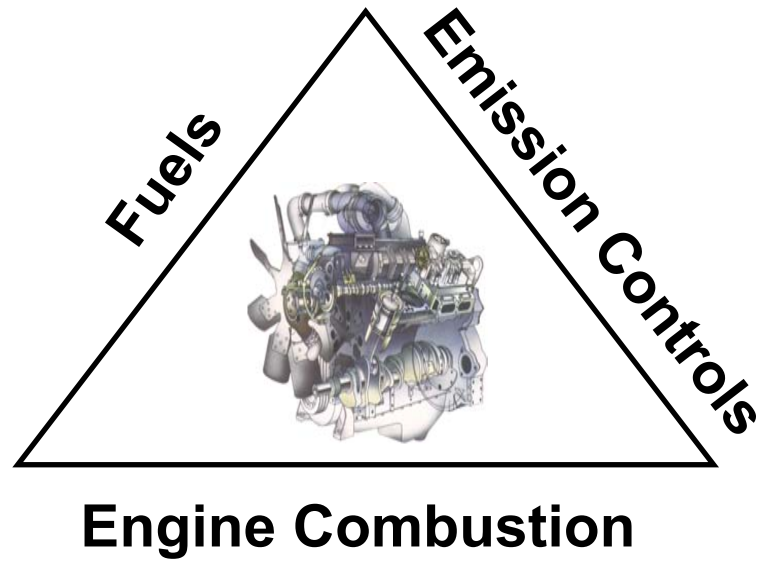
Government
(DOE,EPA,CARB,SCAQMD)

Industry
(Vehicle/Engine Manufacturers, Fuel Providers, API)

What Can Be Accomplished By Working Together

Progress in Reducing Emissions

- Integrated systems approach
- Progress made in all 3 areas
- Partnerships with leading industry suppliers, truck/auto manufacturing, energy companies, and national labs
- Cross-cutting applications



Auto ⟷ Light Truck ⟷ Heavy Truck

Truck NOx Emission Trends

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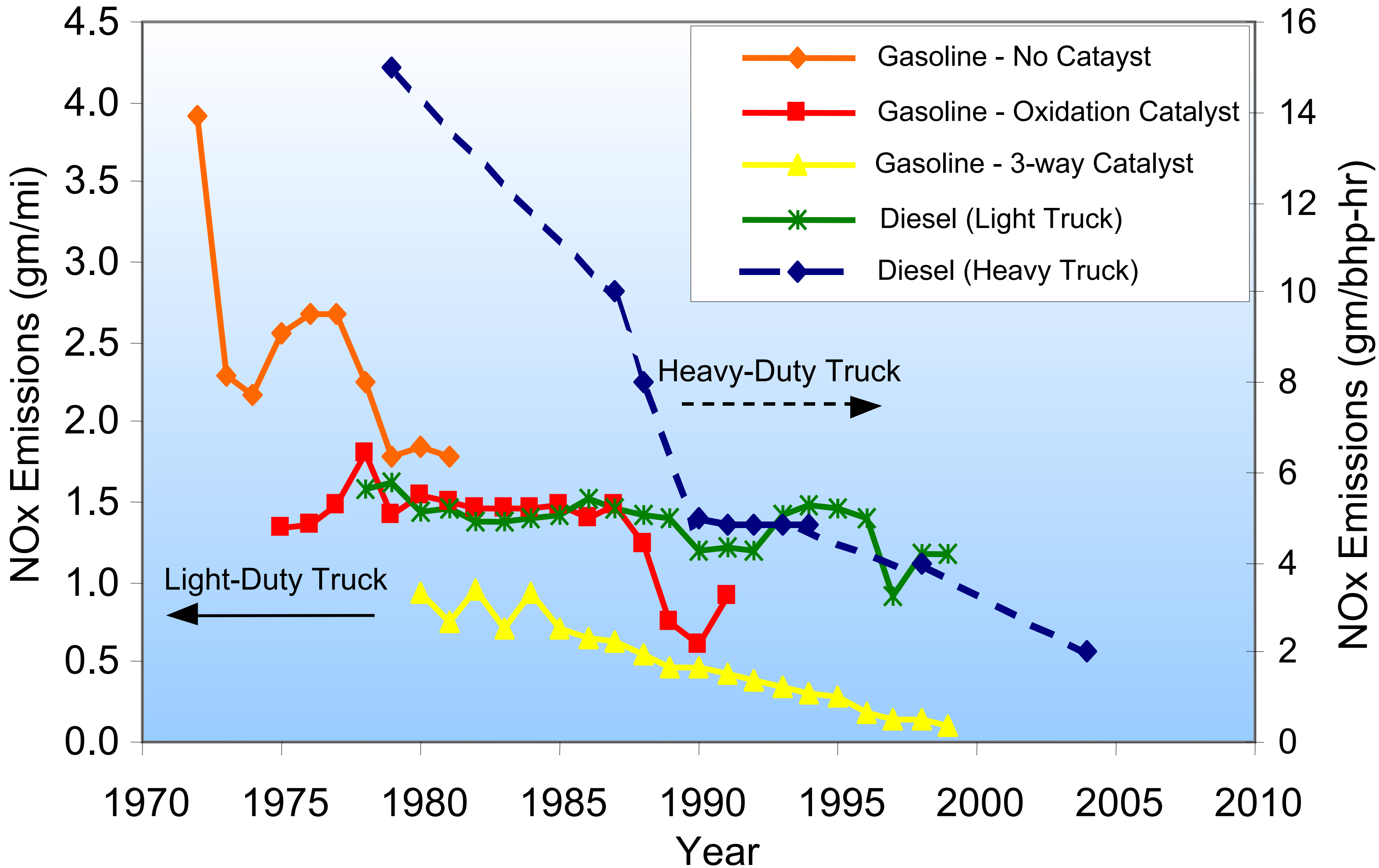

NOx Adsorber Catalyst

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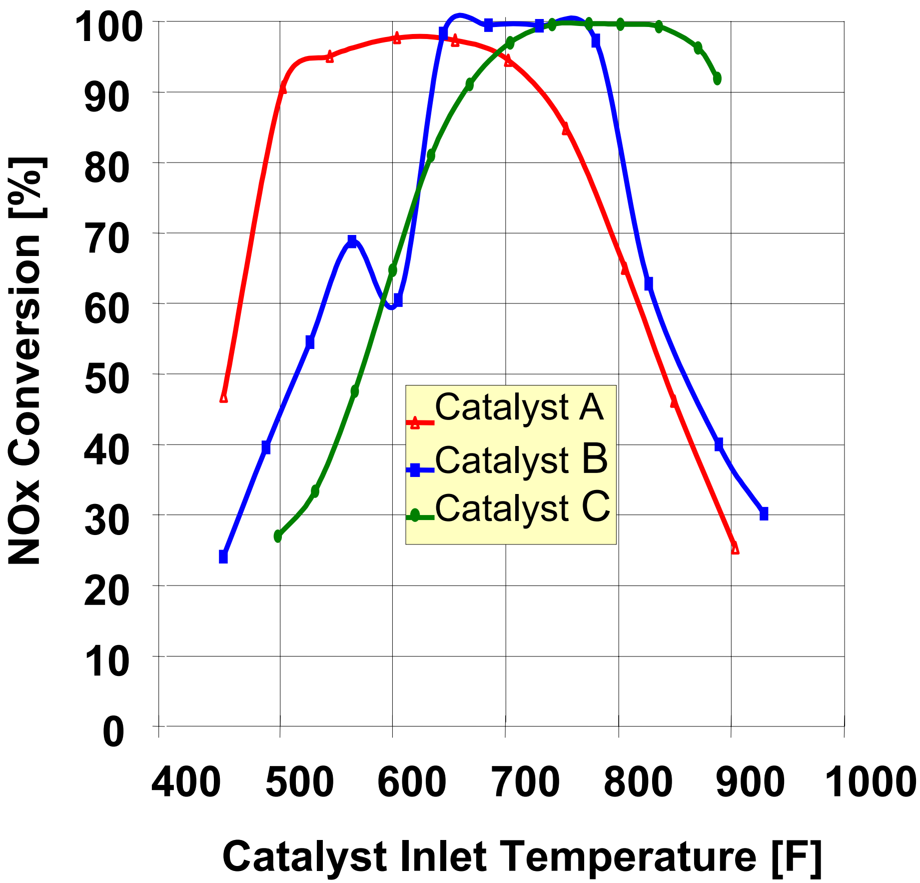
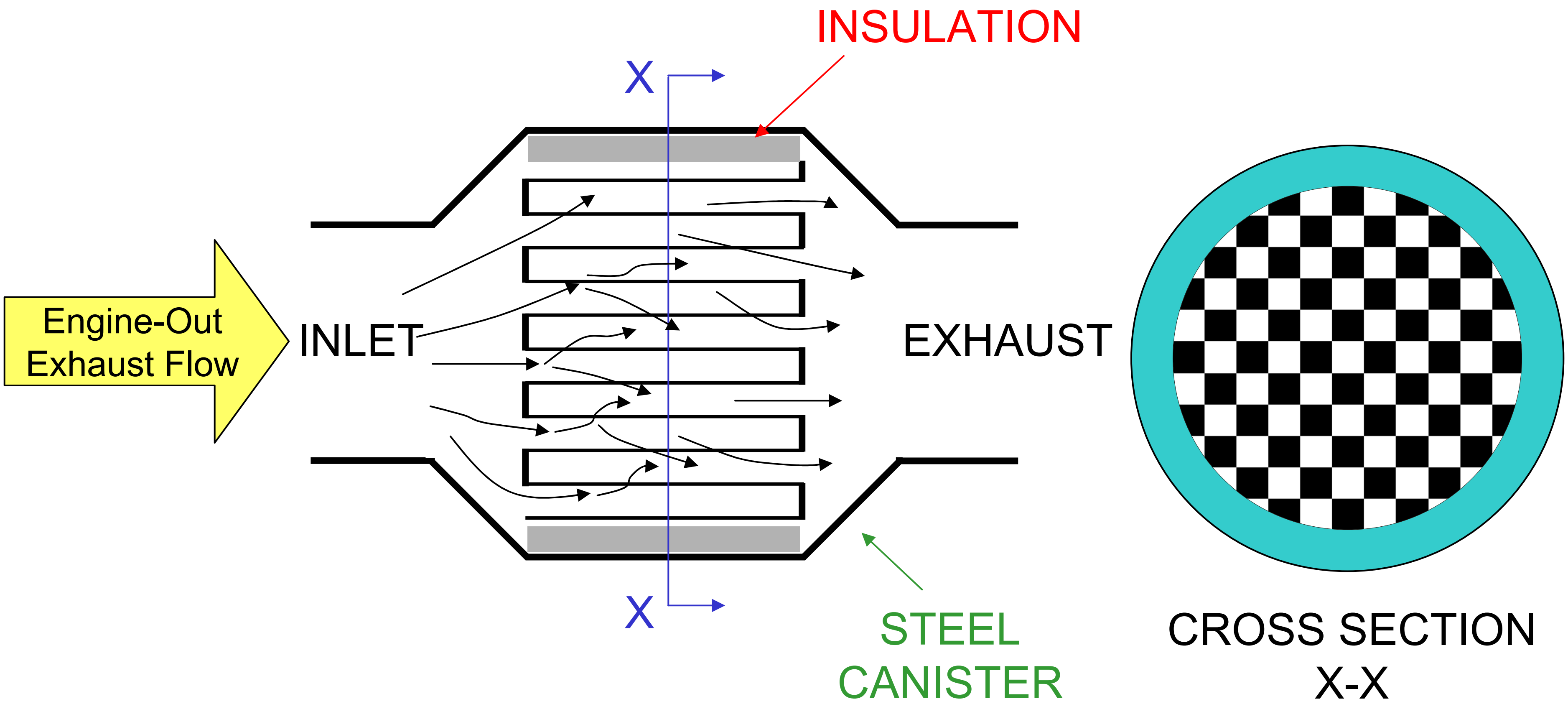


- Up to 98% NOx reduction achieved
- Pre-catalyst injection of diesel fuel
- Fuel penalty 3 to 10%
- Steady state results only
- Sulfur poisons current catalyst chemistry

Source: J. Stang, Cummins Engine Company

Schematic of Catalyzed Diesel Particulate Filter



Automotive Catalytic Converter

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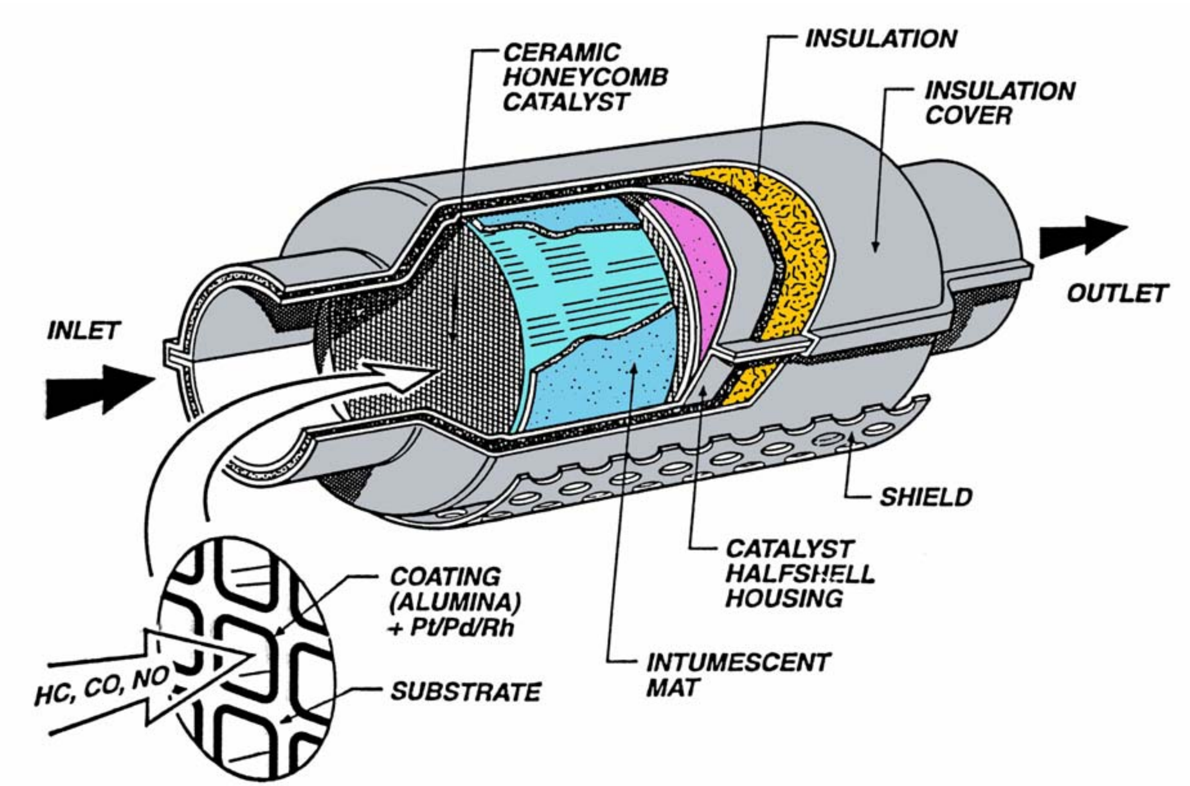

Three Way Catalyst (TWC) Design

ENGELHARD
Change the nature of things.

Nouveau Romanticism

Can There Be Such A Thing As A Clean Diesel?

Debate Between Scientists/Engineers and Environmental Activists

Scientific Approach

- Repeated experimentation, observation, testing
- Methodical but slow

Nouveau Romanticism

- Proof by assertion!
- Quick and easy but likely to lead to bad policy or wrong solution

There is no accountability for poor policy decisions based on emotion and unsupported by scientific evidence or engineering reality.

Emissions with and without Particulate Filters

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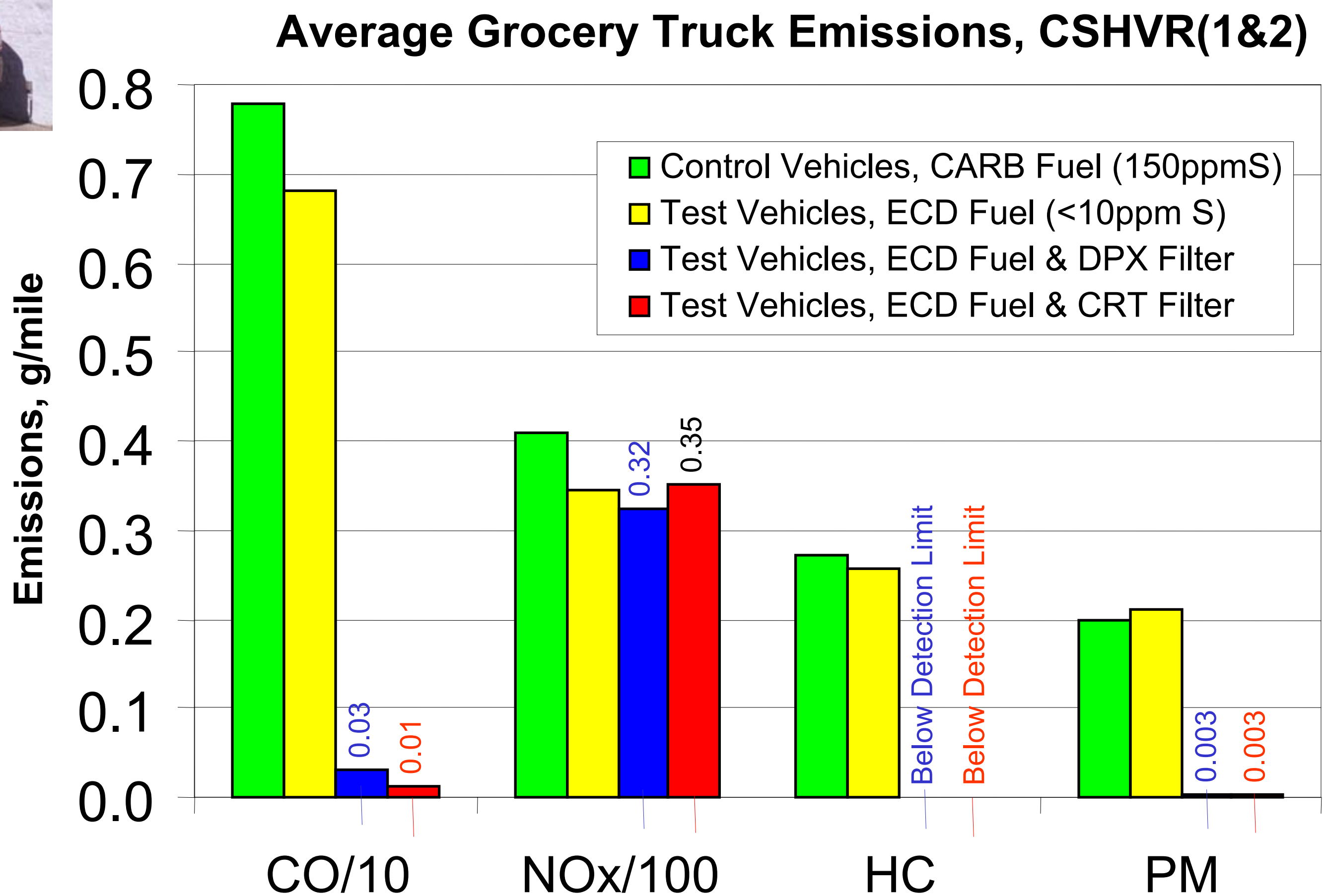

Emissions with and without Particulate Filters

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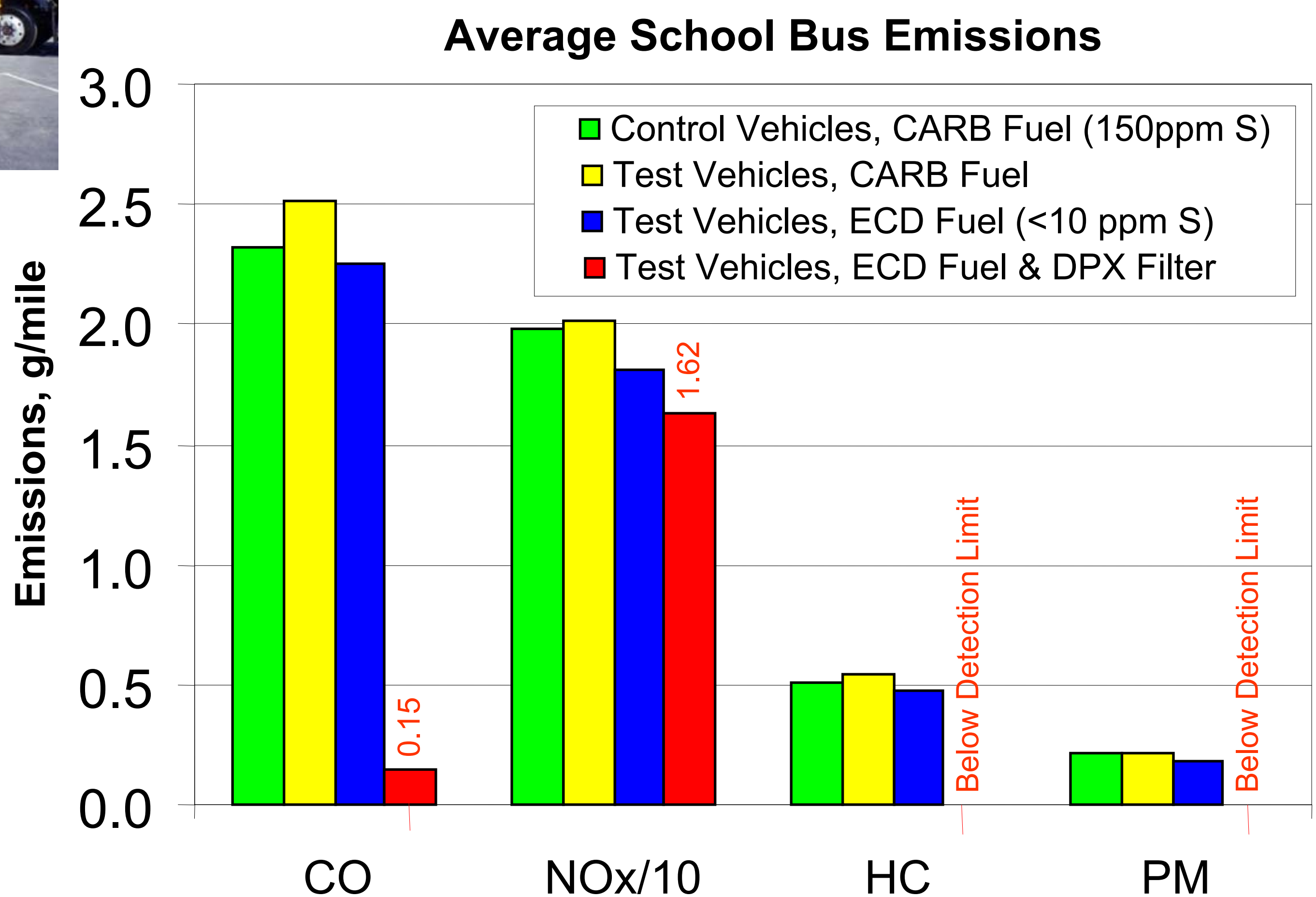

Lower Sulfur Fuel Reduces PM Emissions from Current Heavy-Duty Diesel Engines

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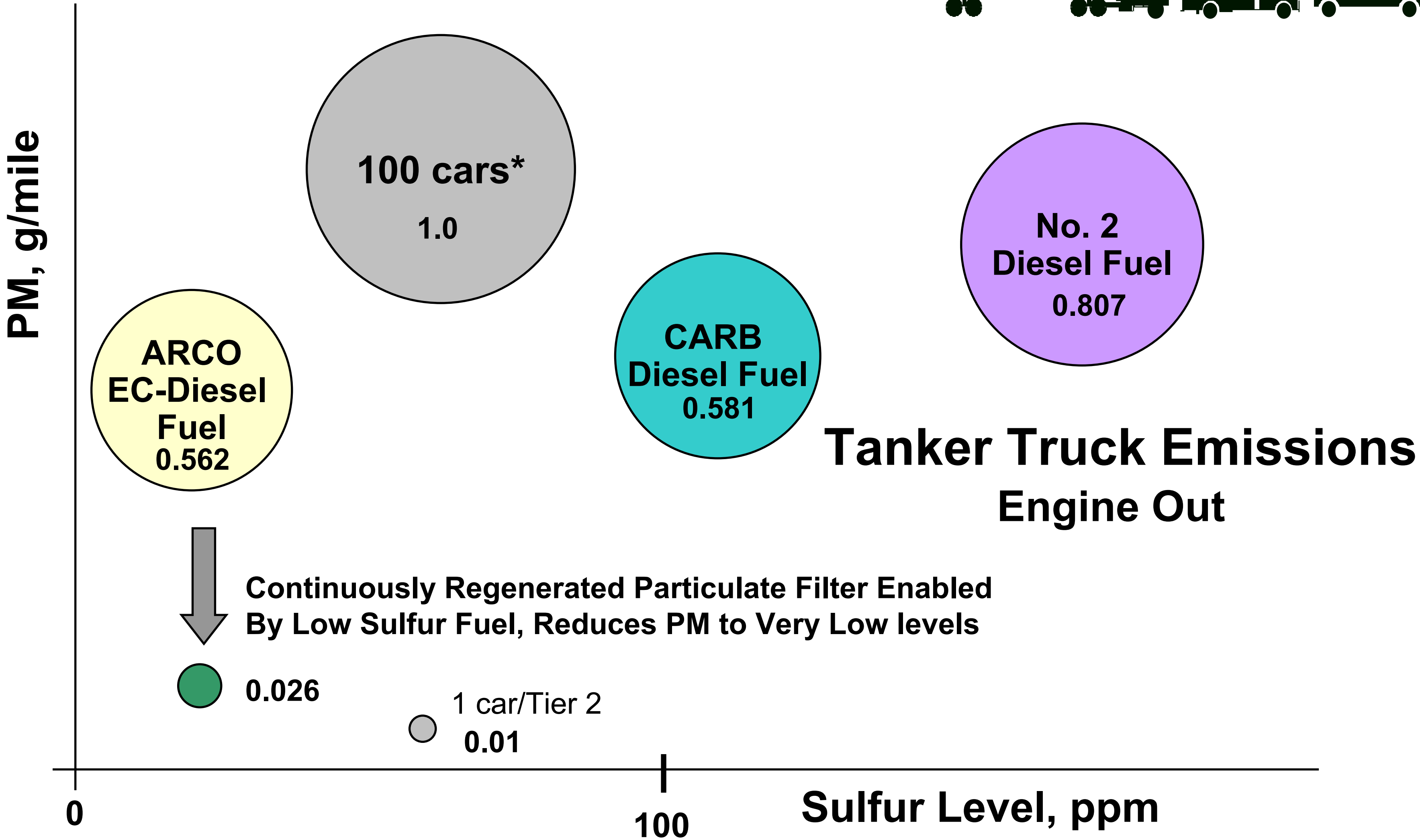

*100 gasoline cars (equivalent work to a tanker truck) each one complying with EPA Tier 2

Source: NREL, Evaluation of ARCO EC-Diesel in California Buses and Trucks

Diesel and Gasoline Emissions Have Similar Mutagenic Activity per Unit Mass

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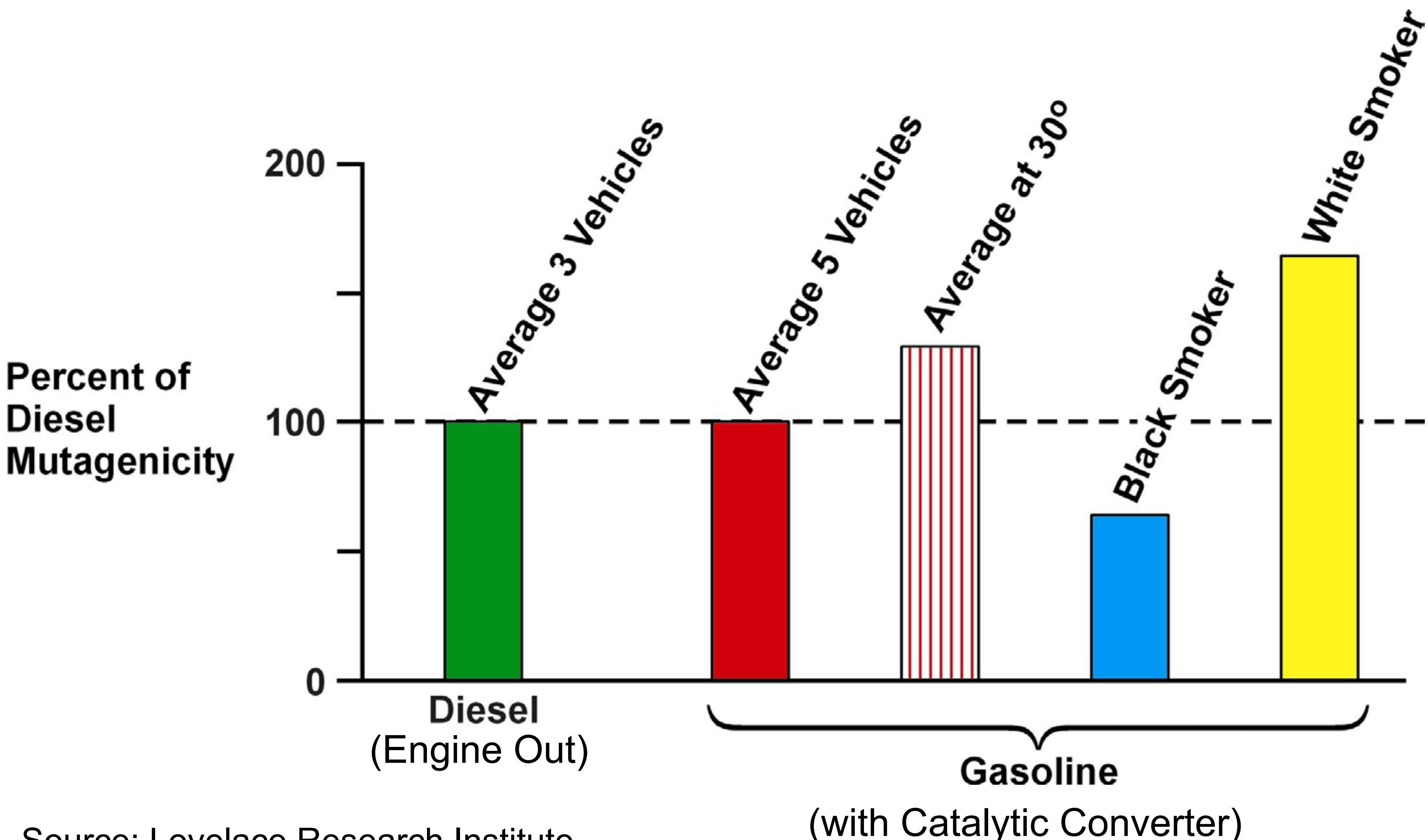

Source: Lovelace Research Institute, *Preliminary Results*

Test Vehicles

Average Diesel (72°F)

- 1998 Mercedes Benz E300
- 1999 Dodge Ram 2500
- 2000 Volkswagen Beetle

Average Gasoline (72°F, 30°F)

- 1982 Nissan Maxima
- 1993 Mercury Sable
- 1994 GMC 1500
- 1995 Ford Explorer
- 1996 Mazda Millenia

Black smoker gasoline (72°F)

- 1976 Ford F-150

White smoker gasoline (72°F)

- 1990 Mitsubishi Montero

*Test Vehicles Used In Lovelace Study

Multiple-Tier Estimates of Carcinogenic Potential

Summary of Preliminary Results

Sample	Mutagenicity	DNA Damage	Chromosomal Damage
Diesel PM 2.5	+	Weak?	Weak?
Diesel SVOC	+	Weak?	Weak?
Gasoline PM 2.5	+	+	+
Gasoline SVOC	+	+	+

- bacterial cell mutagenicity (e.g., Ames test)
- mammalian cell DNA damage *in vitro,*
- chromosomal damage *in vitro*

SVOC – Semi-Volatile Organic Compounds

Interpretation of Preliminary Results

- The Diesel and Gasoline engine exhaust **particulate extracts were mutagenic.**
- The **SVOC extracts were mutagenic** but not so active as their PM2.5 extracts.
- The **Gasoline engine** PM2.5 and SVOC extracts were **active mammalian cell genotoxicants**.
- The **Diesel engine** PM2.5 and SVOC extracts were **inactive or weakly active**.

Summary

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- The transportation sector is almost totally dependent on liquid carbon-based fuels.
- There has been a history of R&D on “promising” alternative transportation energy conversion technologies.
- Vehicle range limitation is a major technological challenge that alternatives must overcome. Cost competitiveness may be the ultimate barrier.
- **Combustion engines are still the most viable energy conversion technologies for future heavy vehicles.**
- Congestion and emissions of criteria pollutants remain national transportation concerns.
- DOE’s integrated three-pronged diesel engine emissions control R&D shows that very low emissions can be achieved without sacrificing engine efficiency and that low sulfur diesel fuel is critical to the commercial viability of advanced emission control technologies.

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Office of Heavy Vehicle Technologies

- The U.S. Department of Energy - Secretary
  - Efficiency and Renewables - Deputy Assistant Secretary, Transportation Technologies
    - **Office of Heavy Vehicle Technologies**
      - Created in the DOE/Office of Transportation Technologies restructuring (March 1996)
      - Focuses research and development on critical areas identified with heavy vehicle customers

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DOE Office of Energy Efficiency and Renewable Energy

Office of Heavy Vehicle Technologies

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Office of Heavy Vehicle Technologies
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Office of Heavy Vehicle Technologies

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Gurpreet Singh
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- **Combustion and Emissions Control**
- **Propulsion System Materials + HTML**

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- **High Strength Weight Reduction Materials**
- **Heavy Truck Auxiliary and Safety Systems**
- **Heavy Hybrid Systems**

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