The Engines That Will Power The Future

Dr. James J. Eberhardt, Director
Office of Heavy Vehicle Technologies
U.S. Department of Energy

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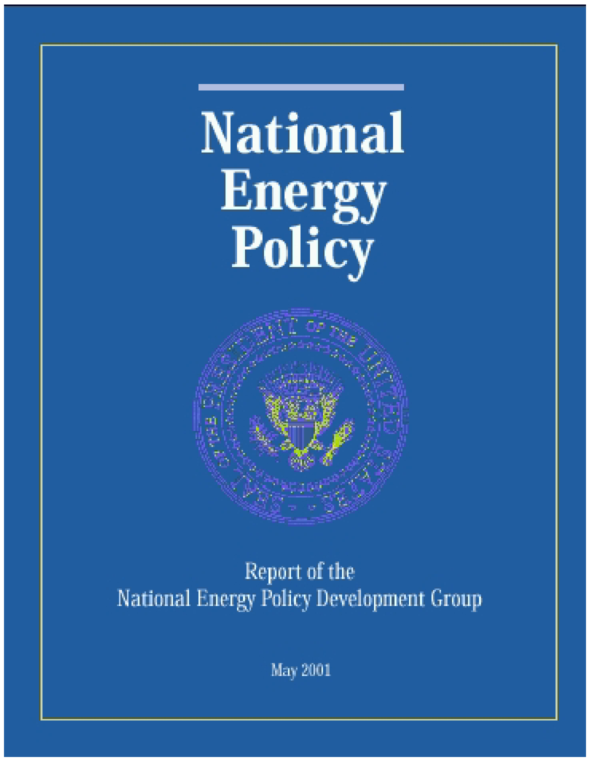
OHVT Mission

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.

The President’s National Energy Policy



“Here we aim to continue a path of uninterrupted progress in many fields…New technologies are proving that we can save energy without sacrificing our standard of living. And we’re going to encourage it in every way possible”

- *Vice President Richard B. Cheney*

Rationale for a Heavy Vehicle Technologies R&D Program

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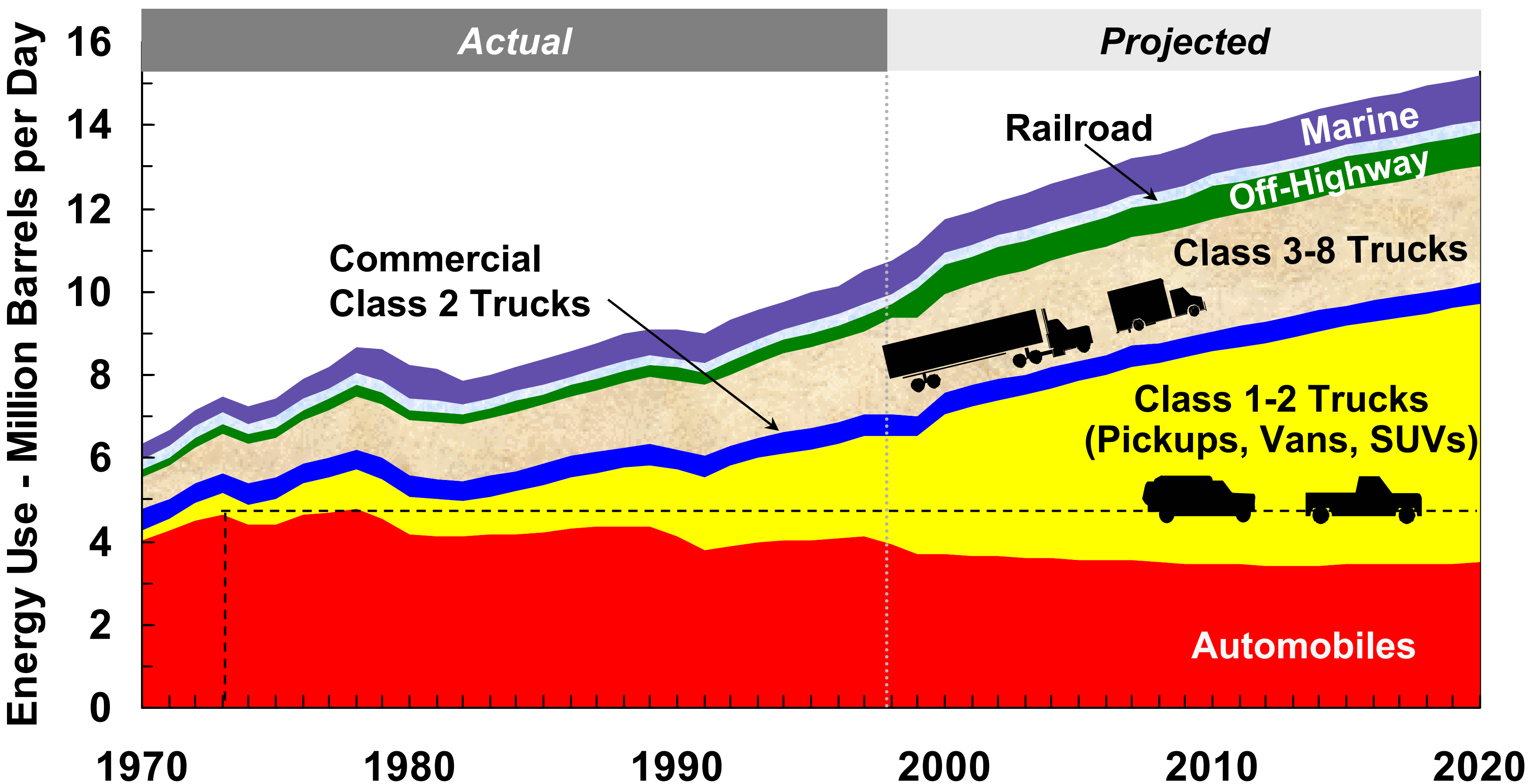
Since the 1973 Oil Embargo All of the Increase in U.S. Surface Transportation Fuel Consumption has been due to Heavy Vehicles



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

The Engines That Will Power The Future

The Question Is Really Not

“What Engines Will Power the Future?”

But, “What Energy Source Will Power Engines of the Future?”

"What Energy Source Will Power Engines of the Future?"

- Presently we know of no energy source which can substitute for liquid hydrocarbon fuels.
- No other fuels:
  - Are so abundant
  - Have such a high energy density
  - Have such a high power density
  - Store energy so efficiently and conveniently
  - Release their stored energy so readily (rapid oxidation/combustion)
  - Have existing infrastructure
  - Are so easily transported

Energy Content of Some Common Fuels

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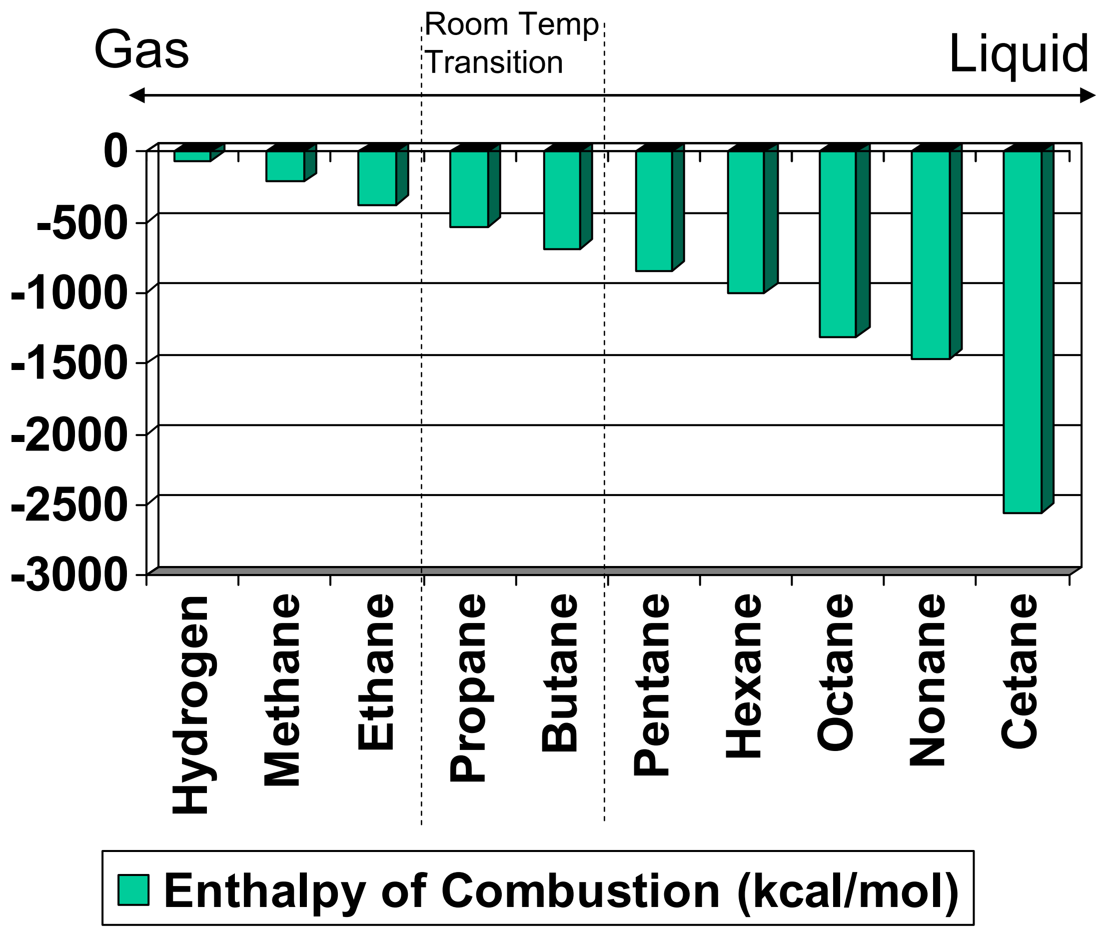
As a chemical storage system, we have no practical substitute for the C-C bond.



Energy Density of Fuels

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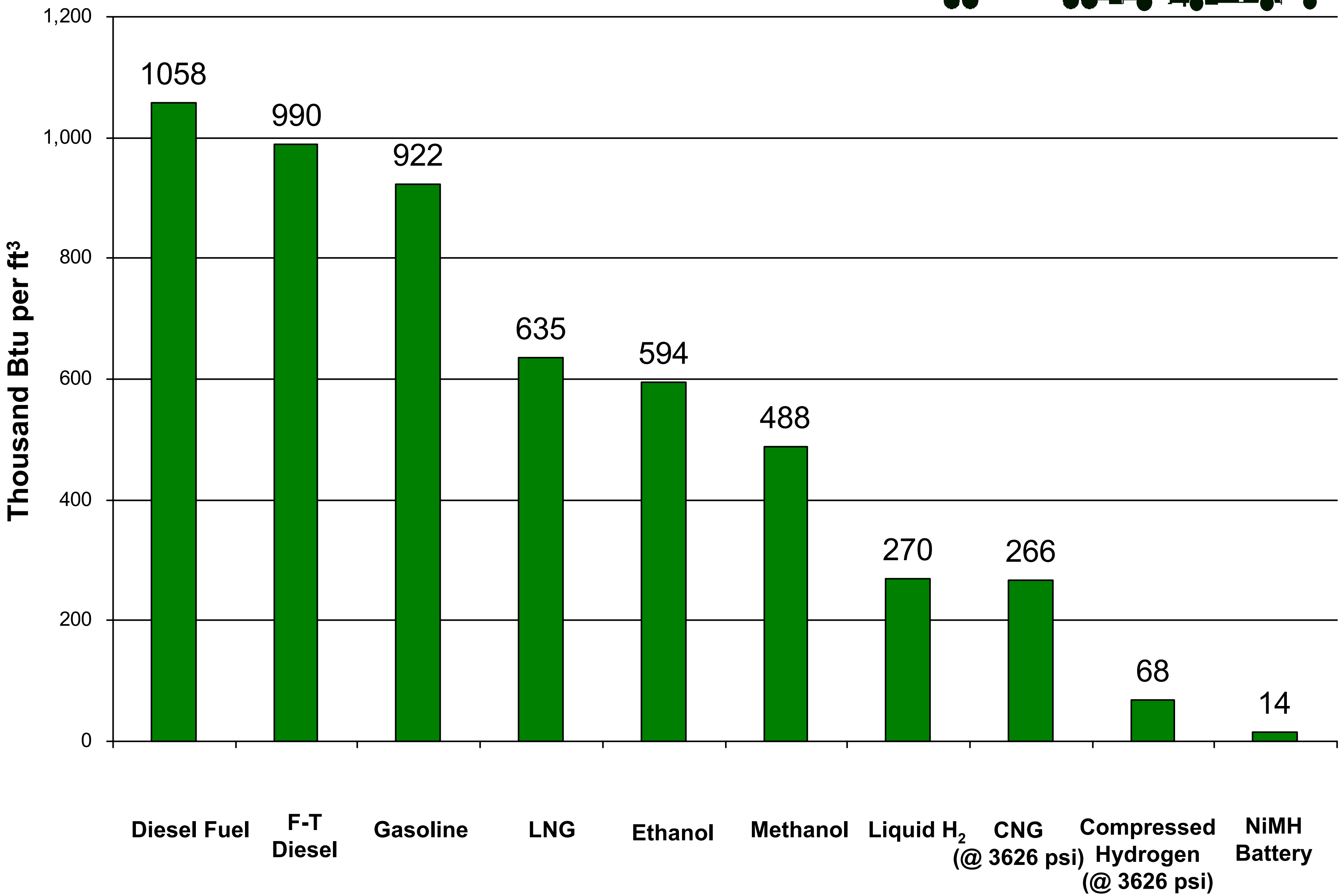

Energy Density of Fuels
Normalized to Diesel Fuel

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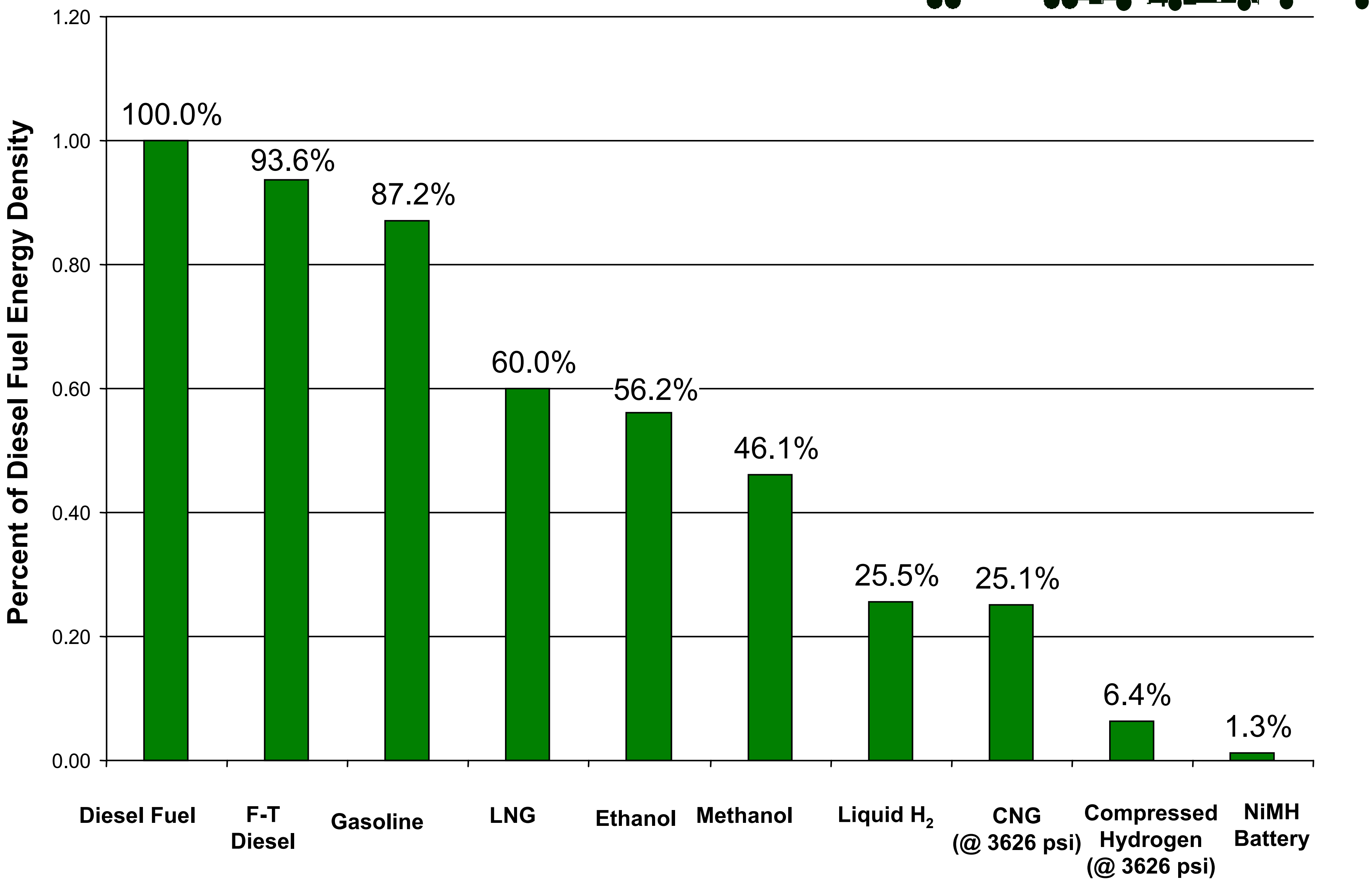

Comparison of Energy Conversion Efficiencies

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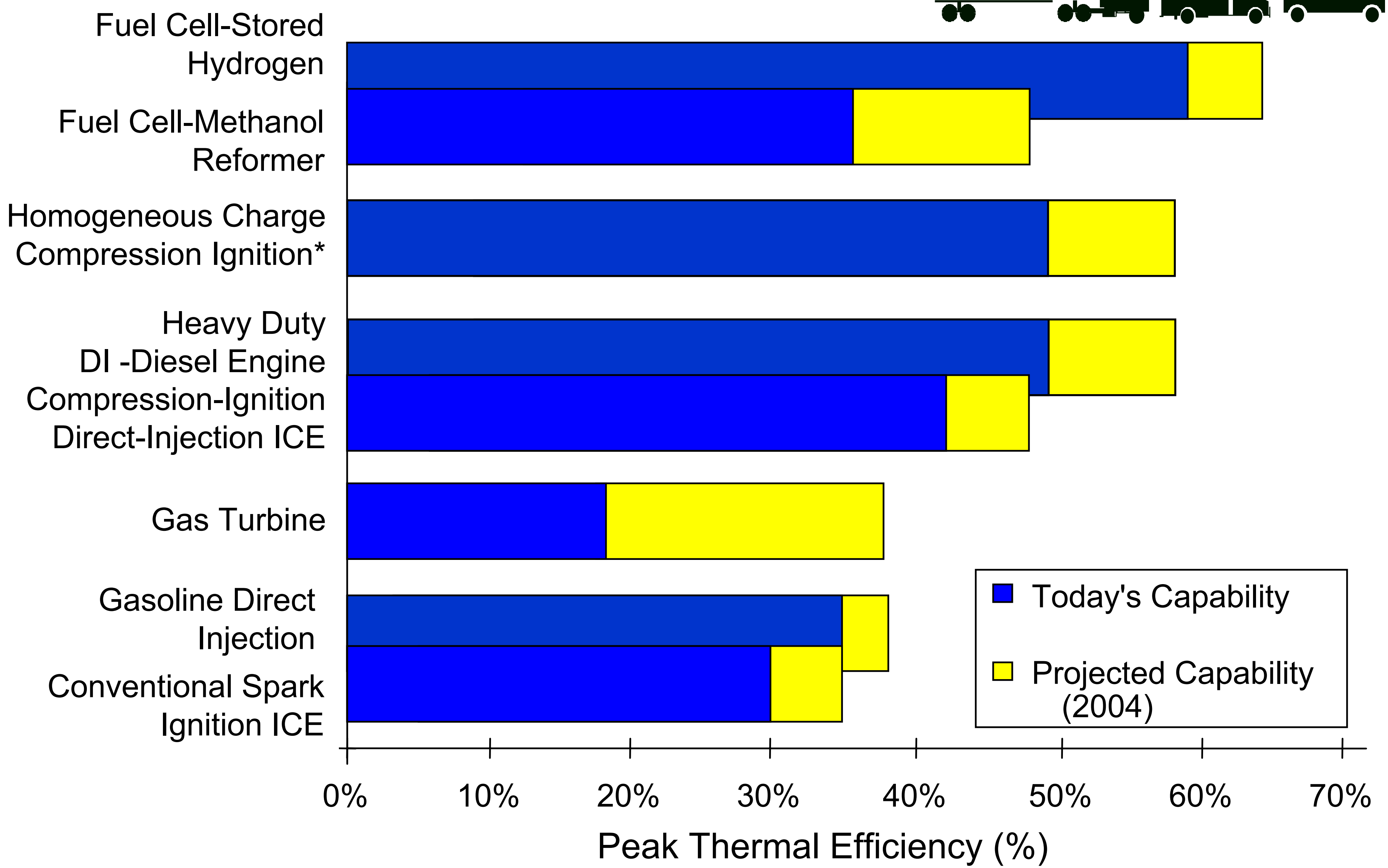

* HCCI research focus: operate well across the load-speed map and extend the operating range to higher loads

Vehicle Range Limitation - Challenge To Be Overcome By Alternatives

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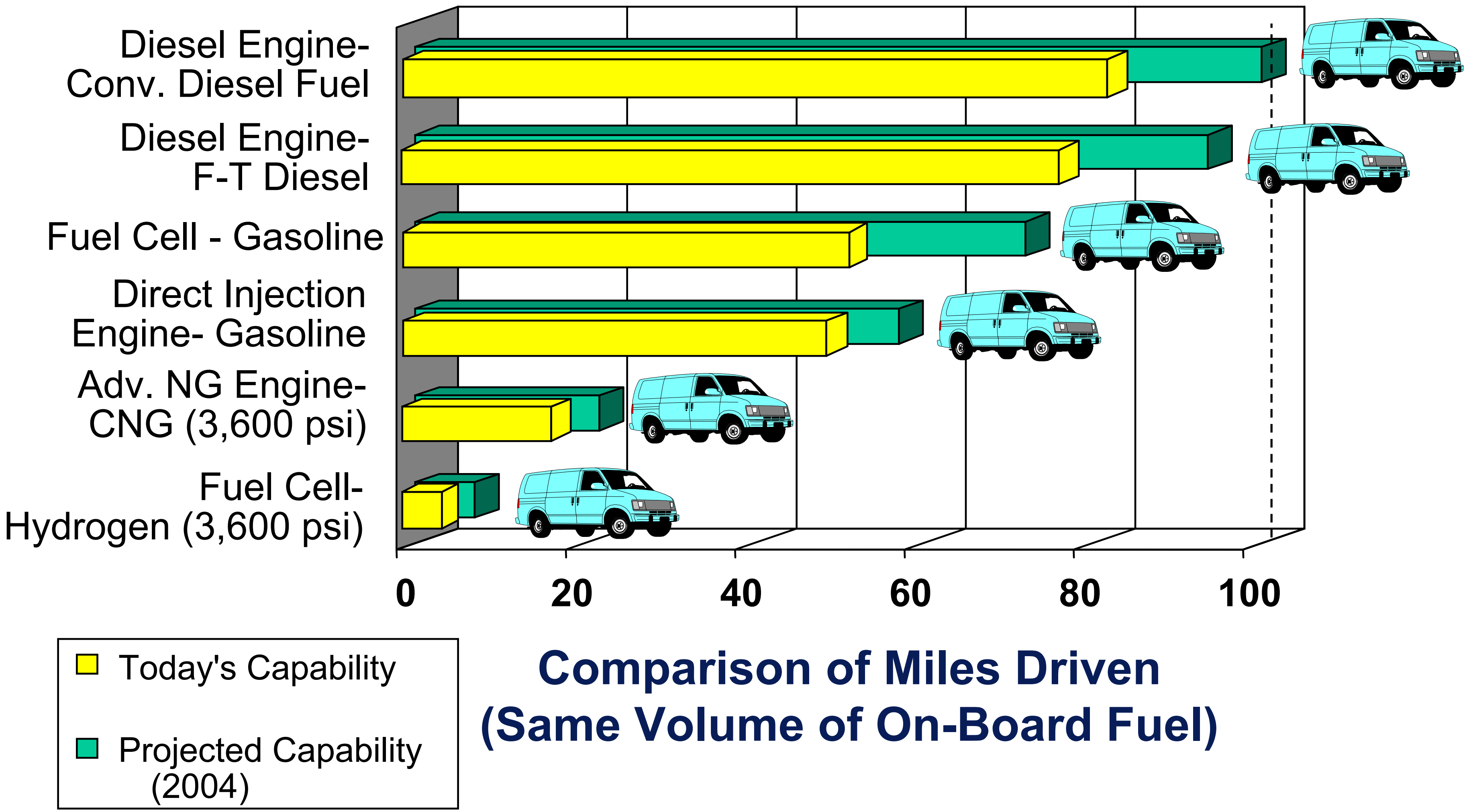
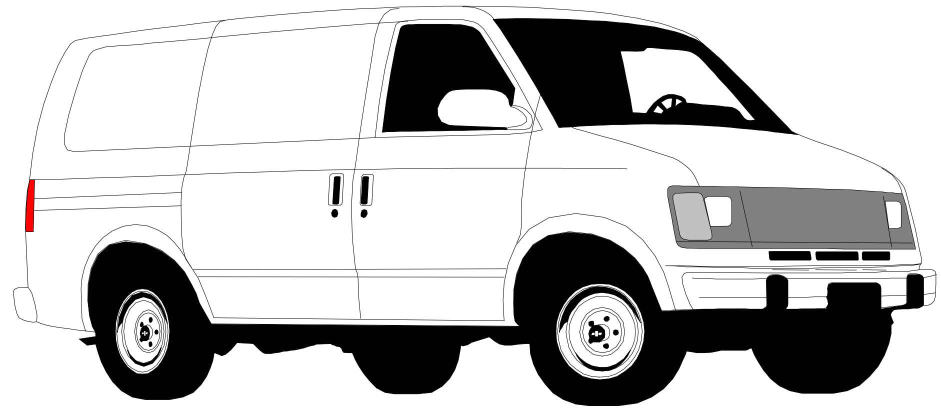


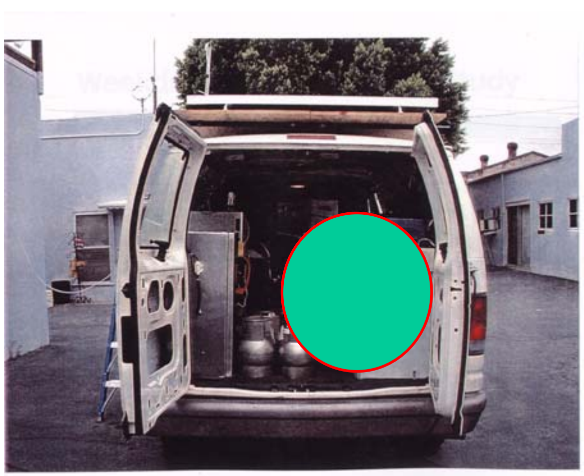
Volume of Fuel Needed for Equivalent Range (480 miles)

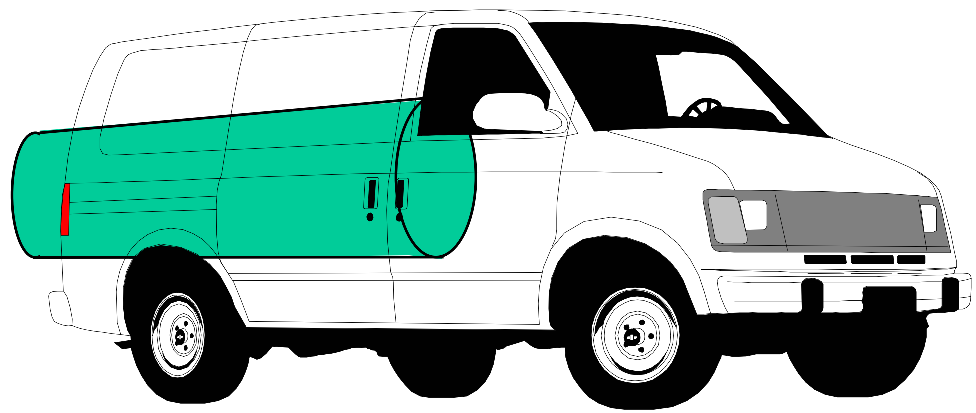
Van cargo space is 190 ft^3 (120”x51”x52”)

Diesel Fueled – 35 gallon tank (same volume as gasoline fueled)



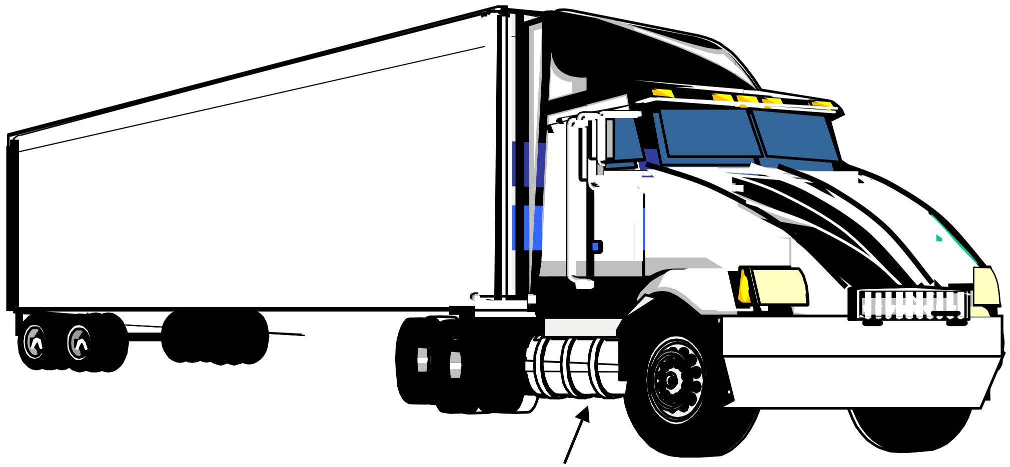
Reduced cargo space!



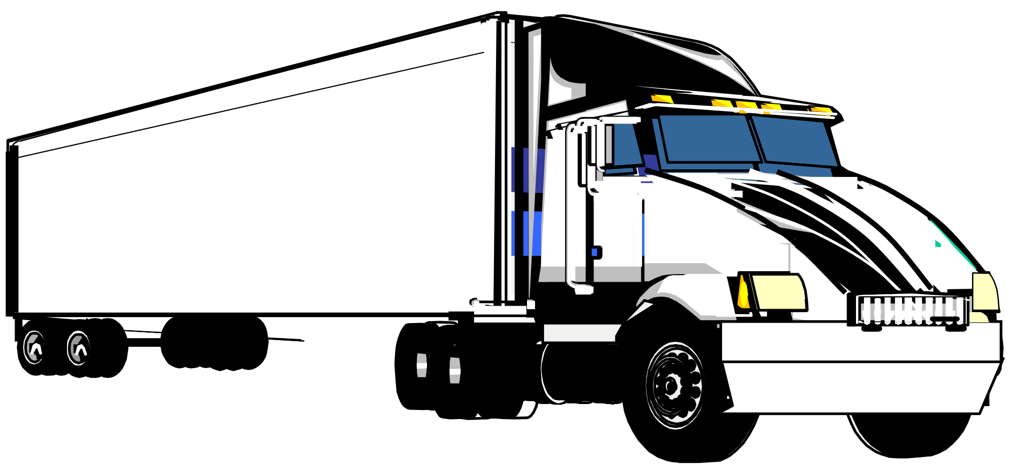


Fuel Cell/Hydrogen Fueled – 490 gallon tank (64 ft^3) at 3,600 psi (Approximate Tank Dimensions L = 108”, D = 36”

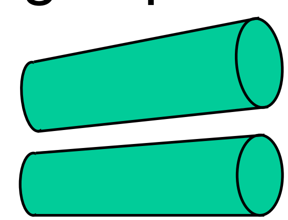
Volume of Fuel Needed for Equivalent Range (1,000 mile range)



Diesel Fueled – Two (one on each side) 84 gallon tanks (23 ft^3)



Loss of revenue cargo space!



Fuel Cell/Hydrogen Fueled – Two 1,180 gallon tanks (316 ft^3) at 3,600 psi (Each tank approximately: L = 150", D = 48")

Space and Weight Estimates for HV Batteries

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Cargo Space in trailer is typically 6,080 ft^3
Front Axle Capacity is 12,000 lb, Rear Axle Capacity is 38,000 lb

LMP Batteries

Performance	Battery Space		Battery Weight	
	(ft^3)	(% of cargo)	(lb)	(% of total capacity)
Range (miles) - 500	358	5.9%	42,635	85%

Assumptions: Truck: 310 HP, 6 mpg fuel economy, 45% average engine thermal efficiency, Batteries: Spec. Power 241 W/kg, Energy Density: 143 Wh/l, Spec. Energy 121 Wh/kg

Renewable Fuels May Have Production Limitations

- In 1998, U.S. highway vehicles consumed 8.11 mbpd of gasoline and 2.01 mbpd of diesel fuel.
- One-tenth of U.S. crop land (460 million acres) would produce sufficient corn for 1.2 mbpd (gasoline equivalent) bioethanol.
- The energy value of corn ethanol is 3,400,530 Btu/bbl (gross), 680,106 Btu/bbl (net) (assuming most efficient fertilizer production, corn production, conversion facilities)
- The approximate heat content for gasoline is 5,250,000 Btu/bbl (gross), 4,846,800 Btu/bbl (net).

- Alternative Fuels for U.S. Transportation, January 2000, prepared for the Transportation Research Board, Committee on Alternative Transportation Fuels, Transportation in the New Millenium
- Tranportation Energy Data Book, Edition 20, October 2000, USDOE, ORNL-6959
- Estimating the Net Energy Balance of Corn Ethanol. By Hosein Shapouri, James A. Duffield, and Michael S. Graboski. U.S. Department of Agriculture, Economic Research Service, Office of Energy. Agricultural Economic Report No. 721 (1995)

Methods to Stretch-out Carbonaceous Resources

Technology and fuel blends will also contribute to extension of petroleum supplies

- High fuel economy vehicles
  - Enhanced SI (VVT, GDI)
  - CIDI (Diesel)
  - Hybrid SI or CIDI
- Biofuels
  - Bioethanol
  - Biodiesel
  - Other bio-oxygenates (ethers, alcohols, esters)
- Carbonaceous materials to liquids
  - Gas-to-Liquid - GTL (methane)*
  - Waste product gasification/GTL
  - Biomass Gasification/GTL
  - Coal Gasification/GTL*
  - Tar sands*
  - Shale*

* Without carbon sequestration, use of this resource could have significant negative environmental impact.

Intermodal Shift of Freight From Truck to Rail

Another way to stretch-out liquid hydrocarbon fuel resource

- More efficient to transport freight using trains instead of trucks
- Rail transport of freight is 3-7X more fuel efficient than freight transported by trucks*
- Rail transport is often not considered because rail transport delivery varies so widely
  - "just in time" manufacturing demands reliability and consistency in timing of deliveries

* Argonne National Laboratory

A Way in Which Carbonaceous Fuels Can Be Stretched Out

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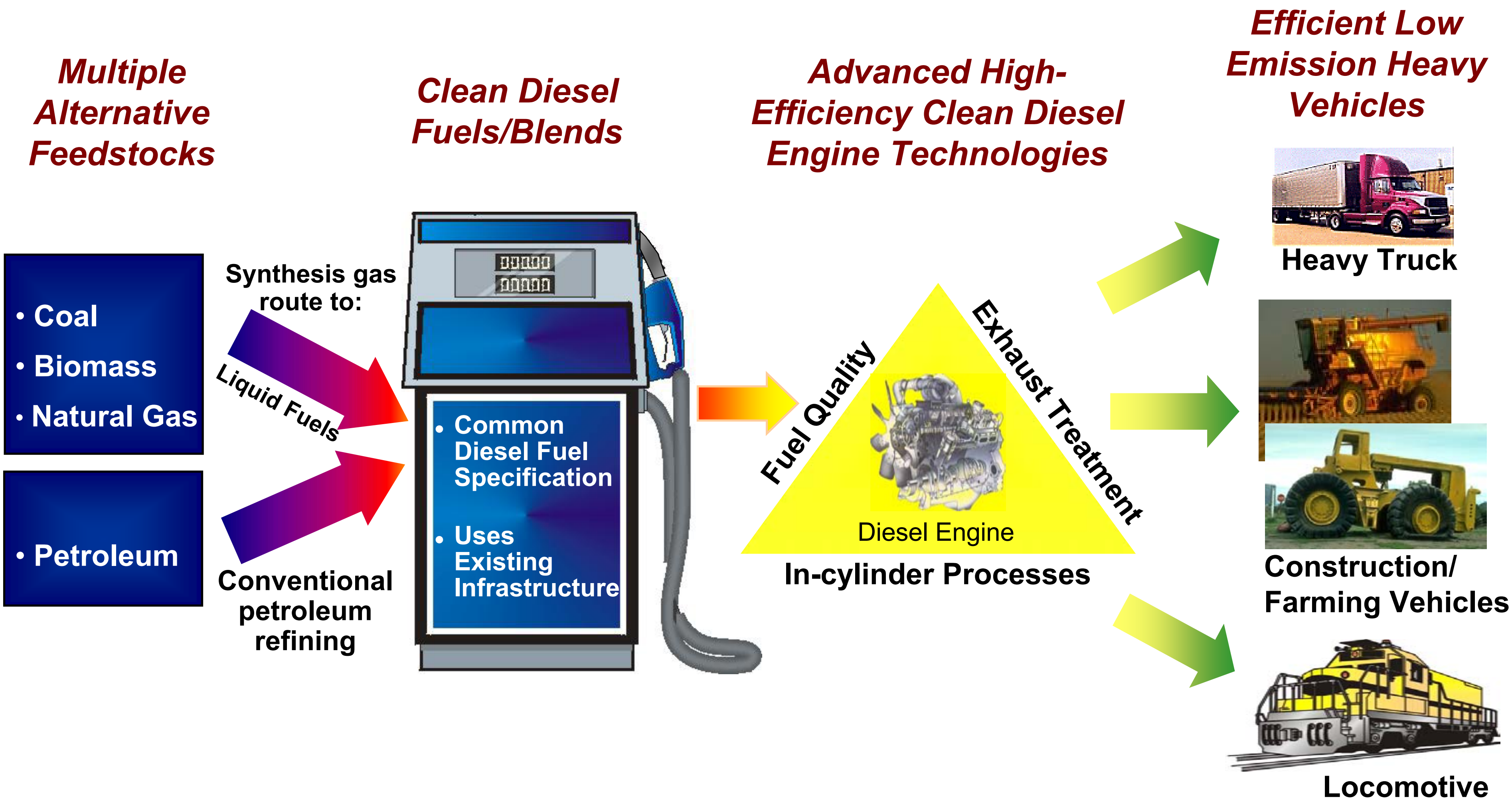
High-efficiency clean diesel-cycle engines utilizing compression ignitable clean fuels/blends derived from diverse feedstocks



Fuels for the Next 10 Years

- Low sulfur diesel fuel (15 ppm) } Dominant
- Low sulfur gasoline (30 ppm) }
- Niche fuels in heavy-duty market
  - Natural Gas (as gas - CNG) – local delivery fleet vehicles
  - LNG (long haul fleet vehicles)
  - Biodiesel (B20) (long haul vehicles, marine applications)
- Natural gas derived liquids
  - Fischer Tropsch (blendstock for petroleum Diesel fuel)
- Ethanol as replacement oxygenate for MTBE in gasoline

CIDI/Heavy Duty Diesel – Increasingly Dominant Engine for Heavy Vehicles

- Improved fuel quality
- Combustion technology
  - DI rate shaping/electronic controls
  - HCCI (part load)
- Aftertreatment technology
- Hybridization

EC-Diesel Technology Validation Program

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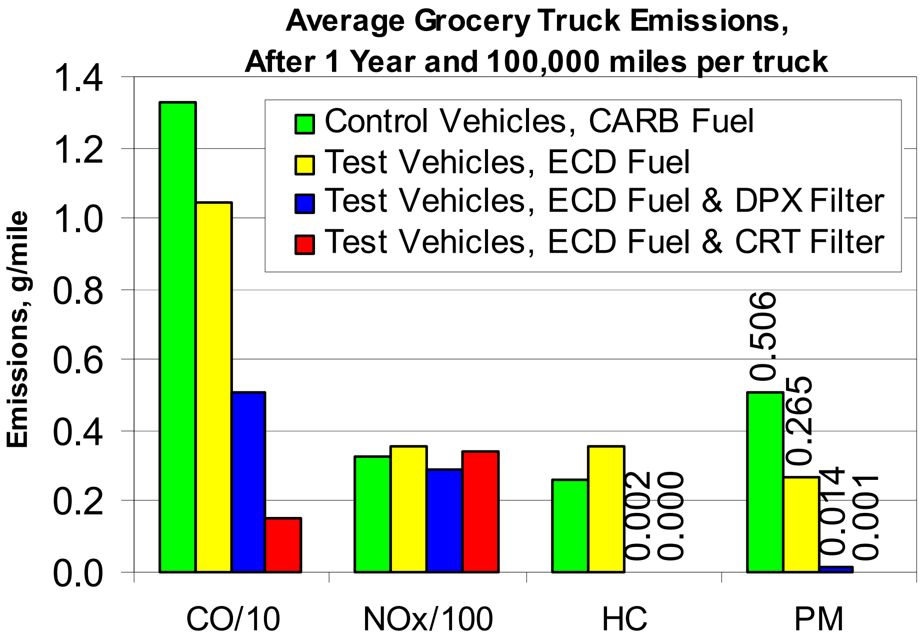
- On-road test of ultra-low sulfur diesel fuel and catalyzed diesel particulate filters (DPFs)
- Partners: ARCO/BP, DOE, NREL, Detroit Diesel, International, Cummins, Engelhard, Johnson Matthey, Ford, CARB, SCAQMD, CEC
- Year-long evaluation to examine performance, cost, reliability, emissions, emissions deterioration
- Six truck and bus fleets tested
- Over 90% PM reduction with essentially no PM deterioration
- Project led to commercialization of ultra-low sulfur diesel fuel and CARB verification of DPX and CRT catalyzed DPFs in California



Potential Energy Carriers

- Currently, we see only 2 potential non-carbon based energy carriers that have the requisite volume needed to replace petroleum fuels
  - Hydrogen
  - Electricity

To Enable Replacement of Petroleum as Primary Energy Carrier for Ground Transportation

Research Breakthroughs Are Needed

- Hydrogen
  - Several major technological breakthroughs are needed if hydrogen fuel cells are to displace the CI/Diesel Engine
    - Electrolytic/water "splitting" Hydrogen Production (renewable, nuclear)
    - Low pressure on-board gaseous fuel storage

    OR

    - On board hydrocarbon fuel reformer
    - Greatly reduced catalyst loading in fuel stack/reformer (cost reduction)
- Major technological breakthroughs are needed if electrical energy is to displace the CI/Diesel Engine
  - Electrical generation from non-fossil resources (renewable, nuclear)
  - On board high energy/high power density electric storage

Summary

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- What Energy Source Will Power Engines of the Near Future?
  - Low sulfur gasoline and low sulfur diesel
- What Energy Carriers Will Power Engines in the distant Future?
  - Major technology breakthroughs are necessary to enable hydrogen or electricity to be competitve with gasoline and diesel fuels
- What Engines will Power the Future?
  - Lacking breakthoughs in the production and on-board storage of non-carbon based energy carriers, incremental improvements in SI and CI/Diesel Engines will ensure continued dominance of the IC engine in the 21st Century.