DEER Conference
Fuels and High-Performance Lubricants
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Efficient Use of Natural Gas Based Fuels in Heavy-Duty Engines

Clean Automotive Technology
www.epa.gov/otaq/technology

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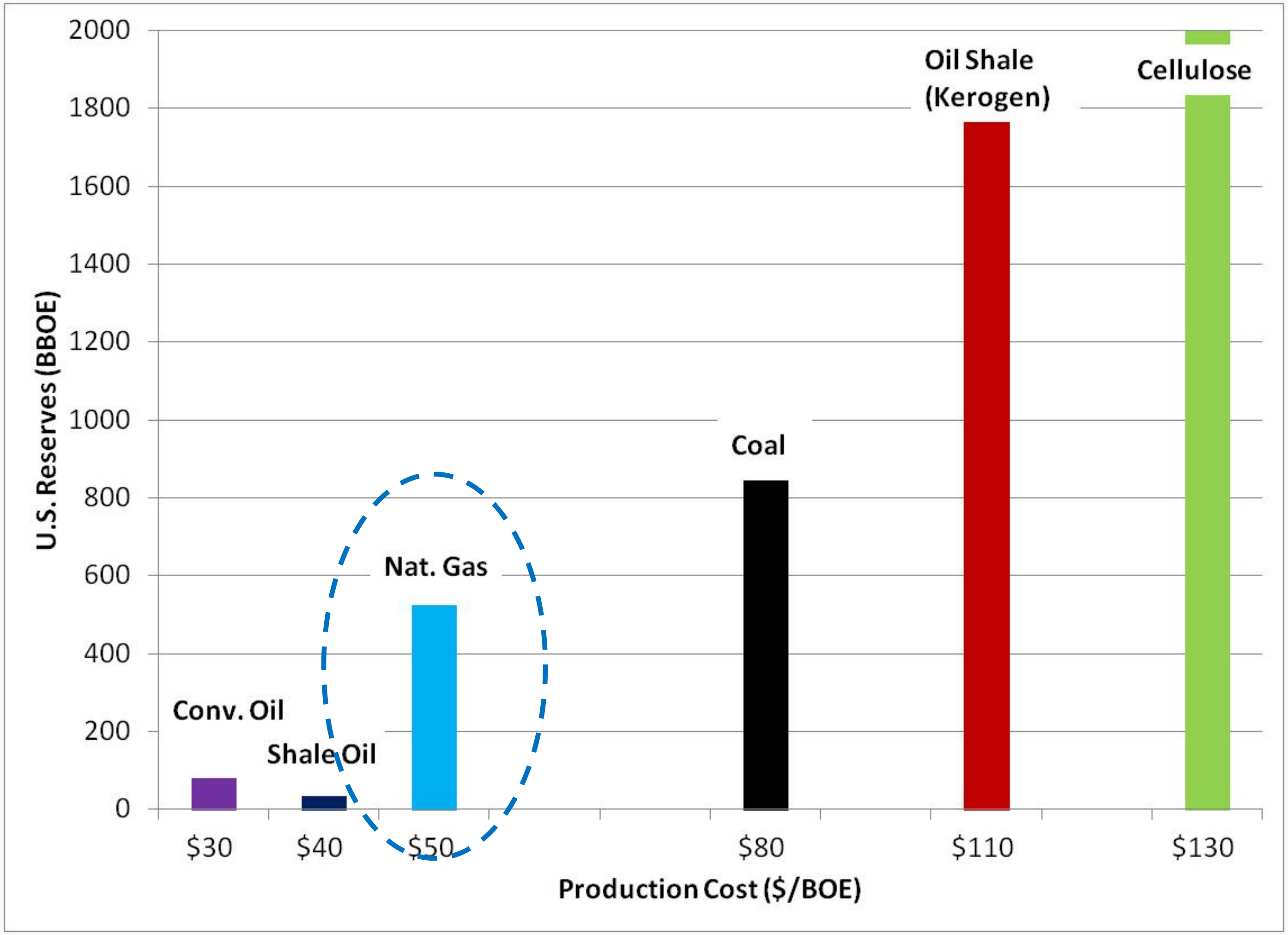
U.S. Environmental Protection Agency

Why Natural Gas as a Transportation Fuel?



Reducing Oil Imports via US Natural Gas

Opposing the "Triple Threat" to the U.S.

- **Preserving Economic Stability**
  - Retaining capital in US economy, creating jobs
  - Investing in US energy infrastructure
- **Guarding National Security**
  - Avoid subsidizing oil imports through our military budget
  - Protecting domestic ownership of US infrastructure
- **Protecting the Environment**
  - Meeting our energy needs while ensuring alternatives achieve national emissions and GHG goals

Using domestic NG resources is critical to meeting these challenges!

Domestic Alternative Fuel Pathways

Feedstocks

- **Petroleum**
  - Conventional
  - Unconventional
  - Tight shale oil
- **Natural Gas**
  - Conventional
  - Shale Gas
- **Biomass**
  - Woody
  - Herbaceous
  - Corn/sugar
  - Fats/oils
  - Wind/solar/renewables
- **Coal**
  - Oil shale (kerogen)

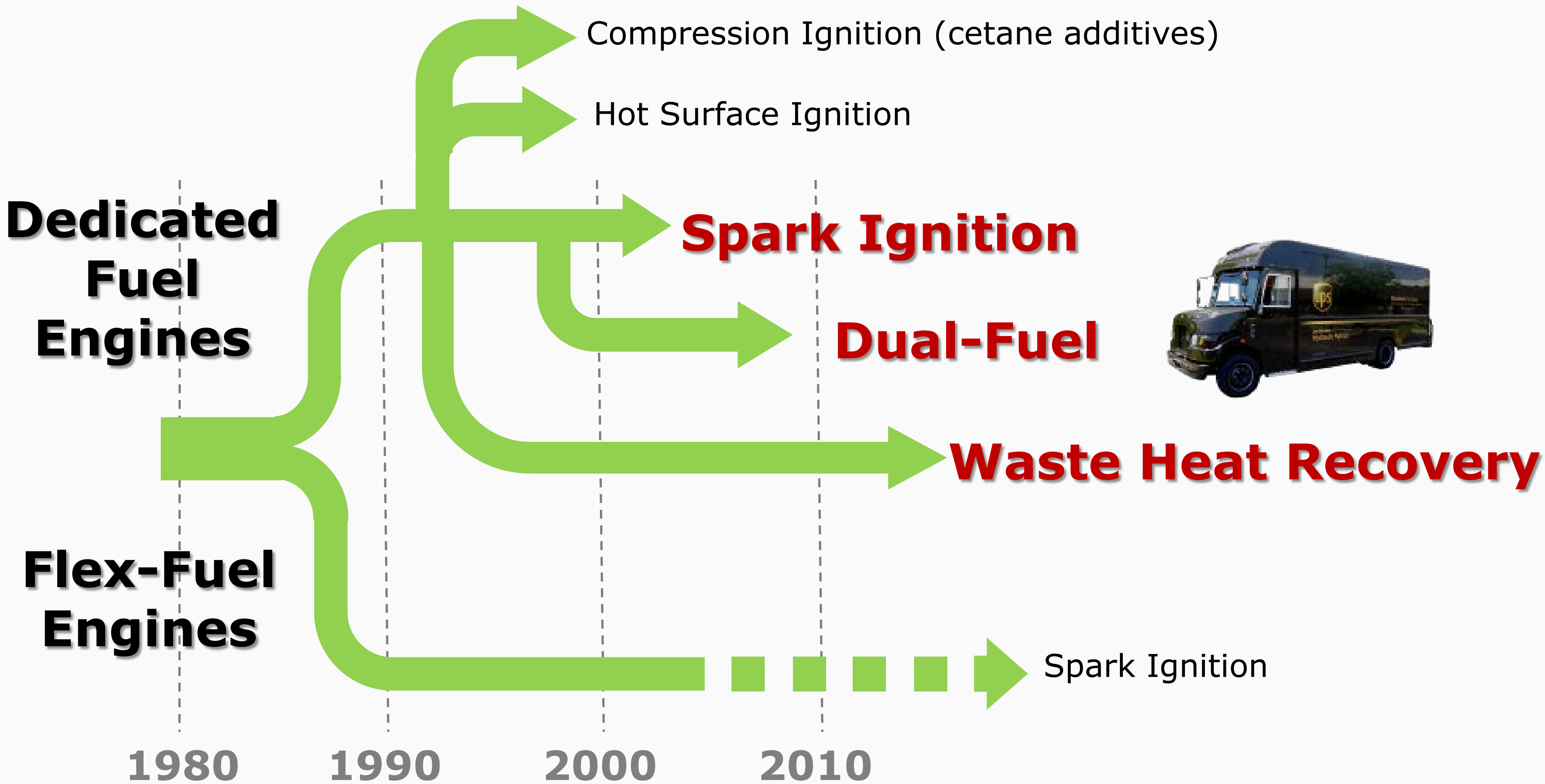
Fuels

- **Gasoline**
  - Conventional
  - MTG
- **Diesel**
  - Conventional
  - Fischer-Tropsch
- **Biodiesel**
- **Ethanol**
- **Methanol**
- **CNG / LNG**
- **Electricity**
- **Hydrogen**

Vehicles

- **Conventional**
- **Flex-fuel**
- **Dedicated fuel**
- **Dual-Fuel**
  - Alcohol
  - CNG
- **EV/PHEV**
- **Fuel cell**

EPA’s Alcohol Engine Research Programs



Technology

Simple upgrade to diesel engine:

- Retain diesel fuel system
- Retain diesel EGR system
- Add 2nd fuel tank for alcohol fuel (ethanol or methanol)
- Add port fuel injection system for alcohol fuel
- Revisions to engine ECU
- DPF may be necessary

No NOx aftertreatment necessary

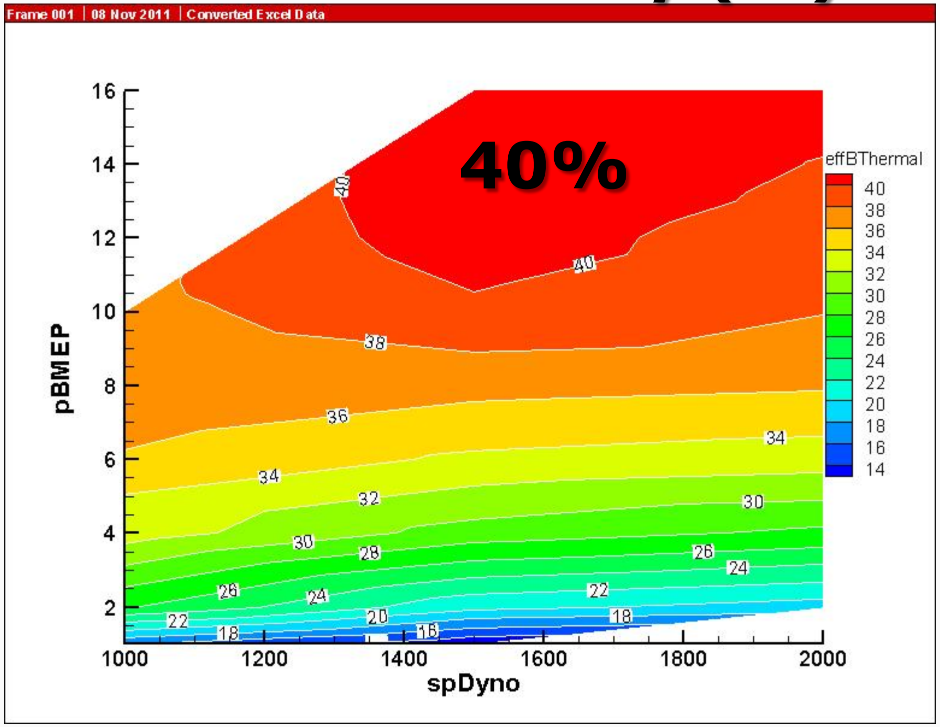
Around 5% more efficient than today's diesel engines

Dual-Fuel Engine

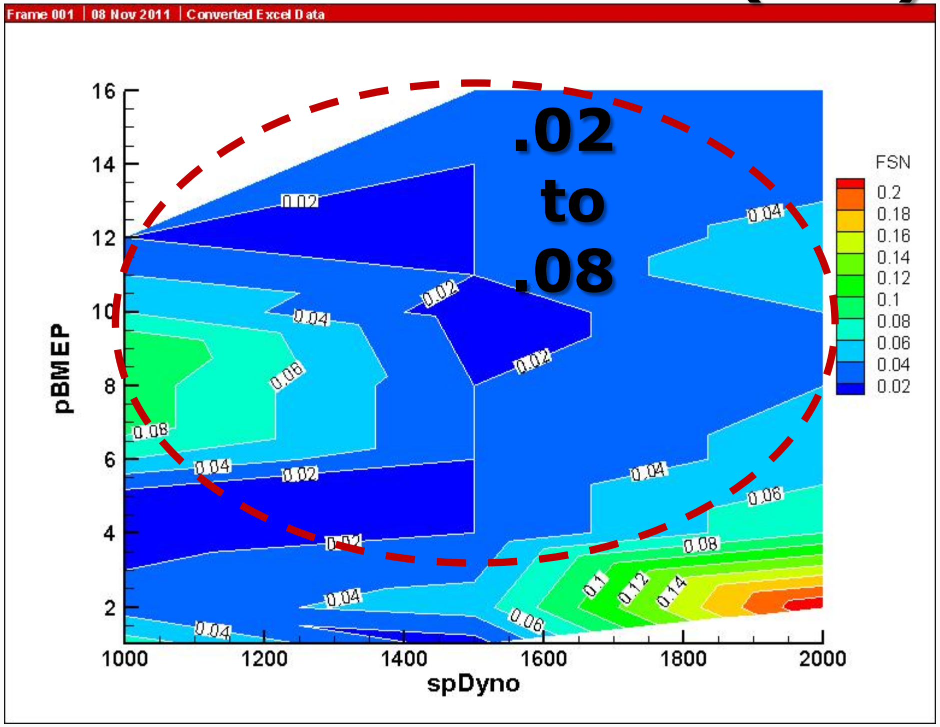
Diesel-Methanol (M100)

*Calibrated to **0.27 g/kWh NO_x***

Brake Efficiency (%)



Particulate Emissions (FSN)

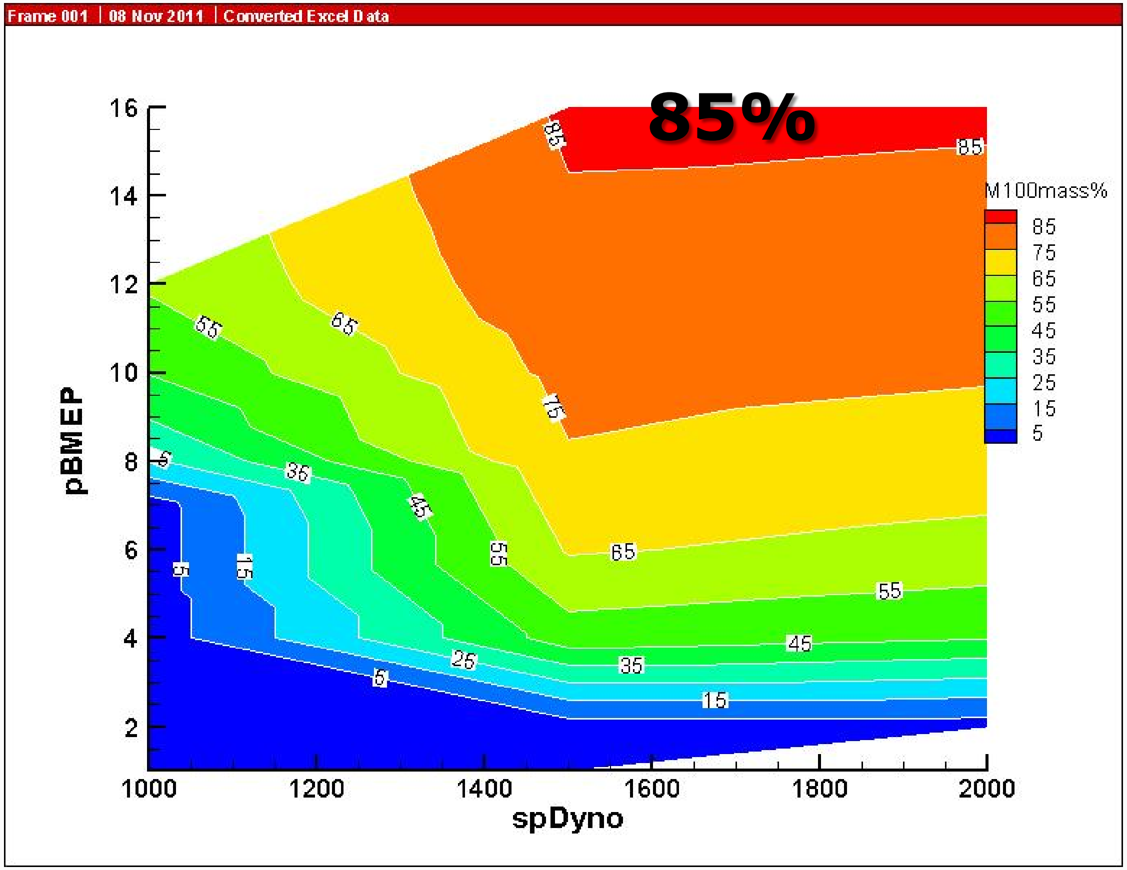


Results from EPA's initial engine calibration

Dual-Fuel Engine

Diesel-Methanol (M100)

M100 Substitution Ratio (mass basis)



- **Results are from initial engine dyno calibration**
- **We have also seen results with 90% peak efficiency**
- **With a better fuel injection strategy the substitution ratio would increase during lower power operation**

Dual-Fuel Engine

Diesel-Methanol versus CNG

Estimated Fuel Economy

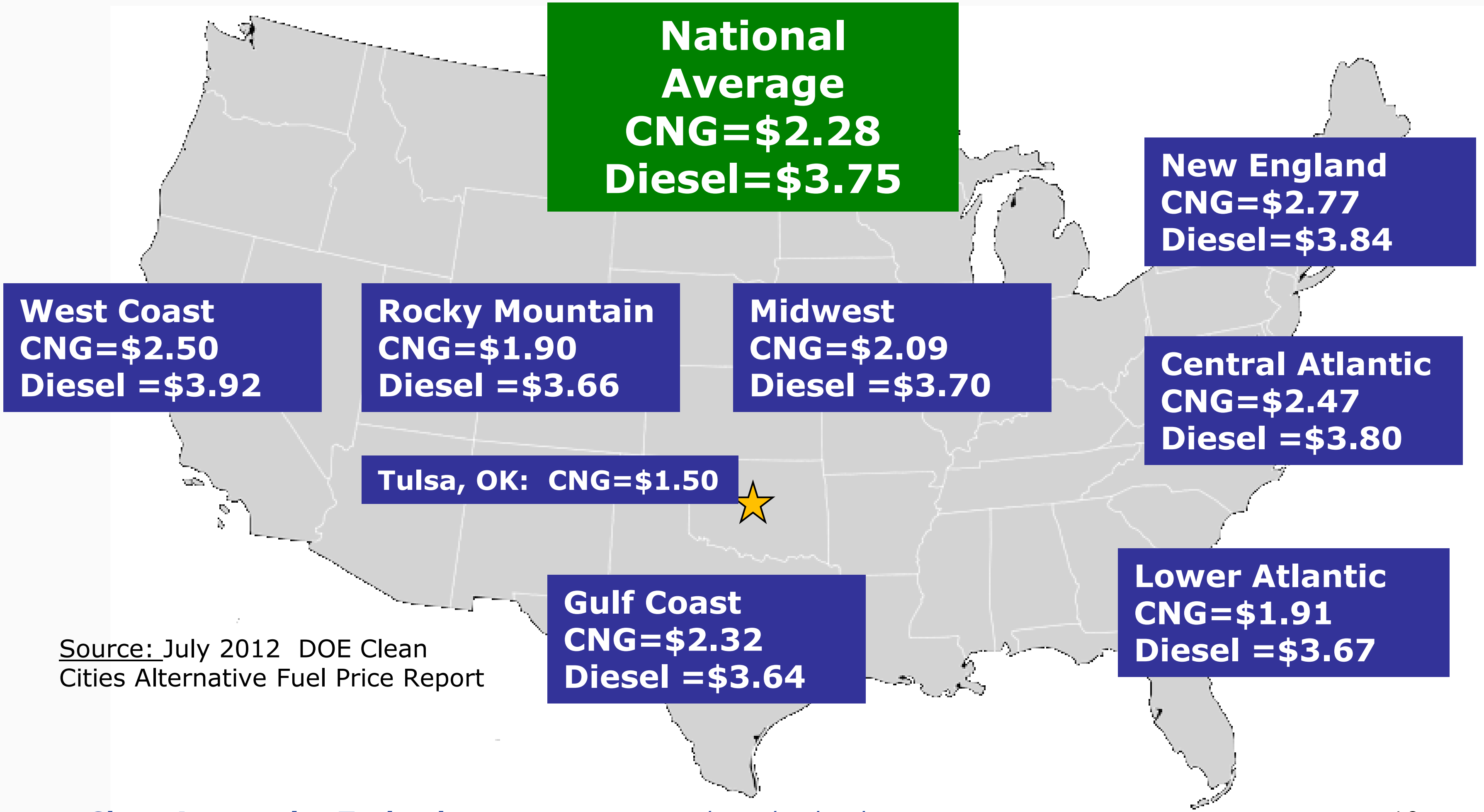
CNG	Diesel-Methanol
5.1 mpg (class 8) **7.0 mpg*** (class 6)	**6.3 mpg** (class 8) **8.4 mpg*** (class 6)
Uses gasoline-engine technology • Throttled, spark ignition • Around 15% less efficient than today's diesel	**Uses diesel engine technology** • No throttle, compression ignition • No SCR fuel penalty • Around 5% more efficient than today's diesel engines

Baseline diesel: 8.0 mpg (class 6), 6.0 mpg(class 8)

**Assumes a typical EPA City cycle, which favors dual-fuel approach (no throttling, better idle fuel economy)*

Regional variation in retail fuel prices (July 2012)

Diesel Gallon Equivalent (DGE) basis



Source: July 2012 DOE Clean Cities Alternative Fuel Price Report

Estimating Operating Costs

Global price variability: Unsustainable Differences

World LNG Estimated May 2012 Landed Prices

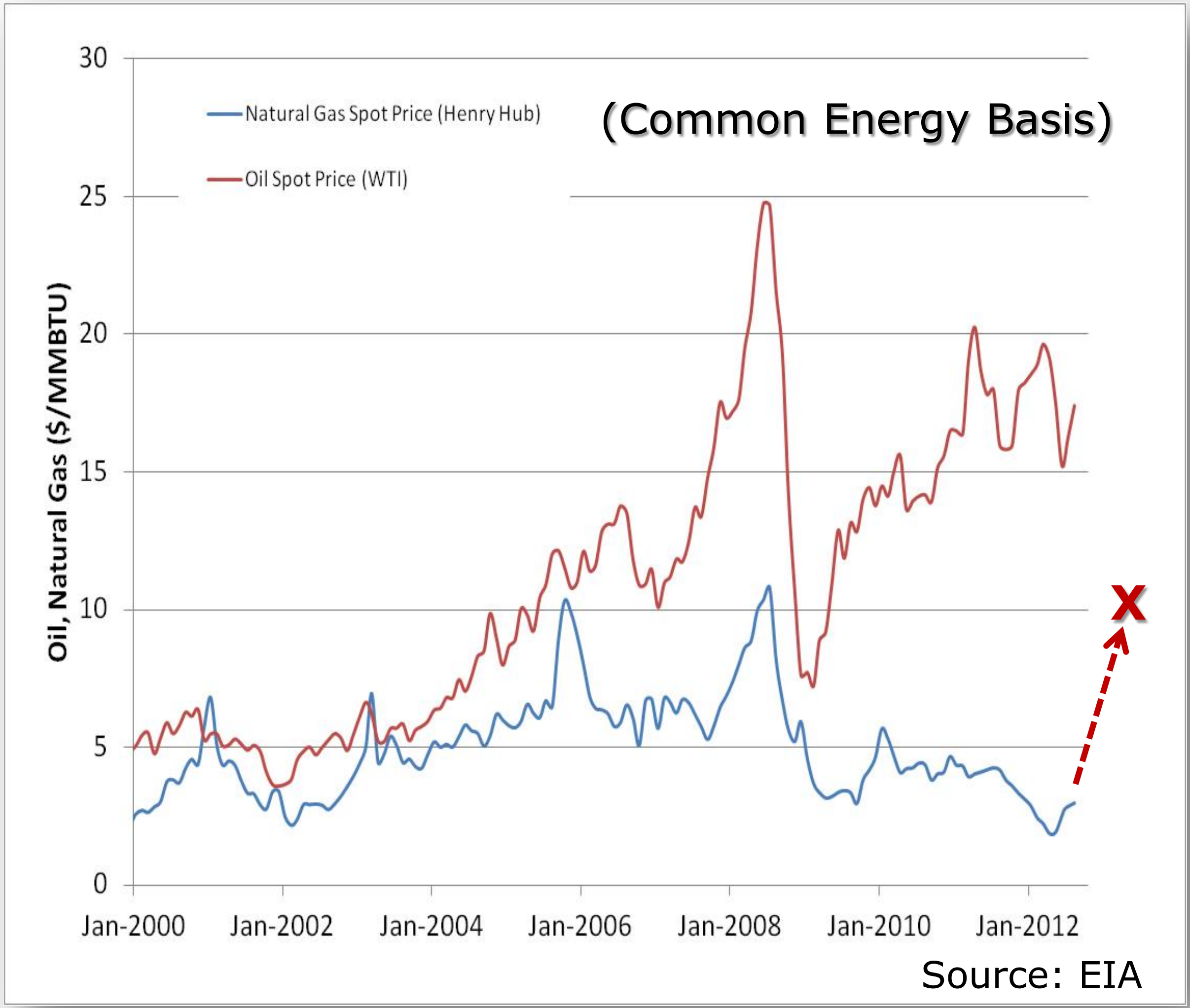
"The solution to low prices is… low prices."

concluding remark at EIA workshop August 23, 2012

Source: Waterborne Energy, Inc. Data in $US/MMBtu

Updated: April 19, 2012

Natural Gas vs. Crude Oil Price

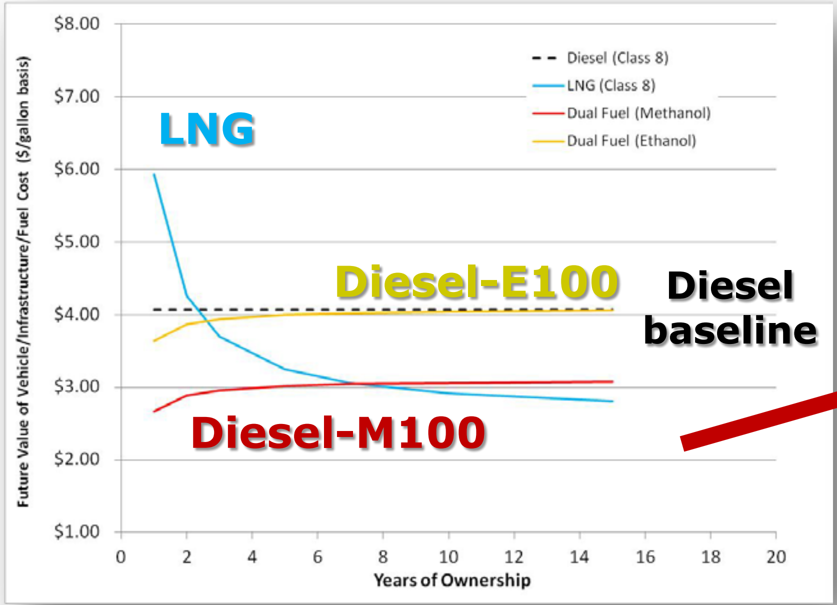


- Historic price relationship between NG and Crude would suggest that the commodity price of NG should be around $10 / MMBTU
- Expect NG prices to eventually return to historic relationship as demand for NG increases
  - ✓As coal electric power plants are converted to NG, and
  - ✓As the LNG export market comes on-line
  - ✓With balanced production versus demand relationship

Dual Fuel Methanol-Diesel versus LNG

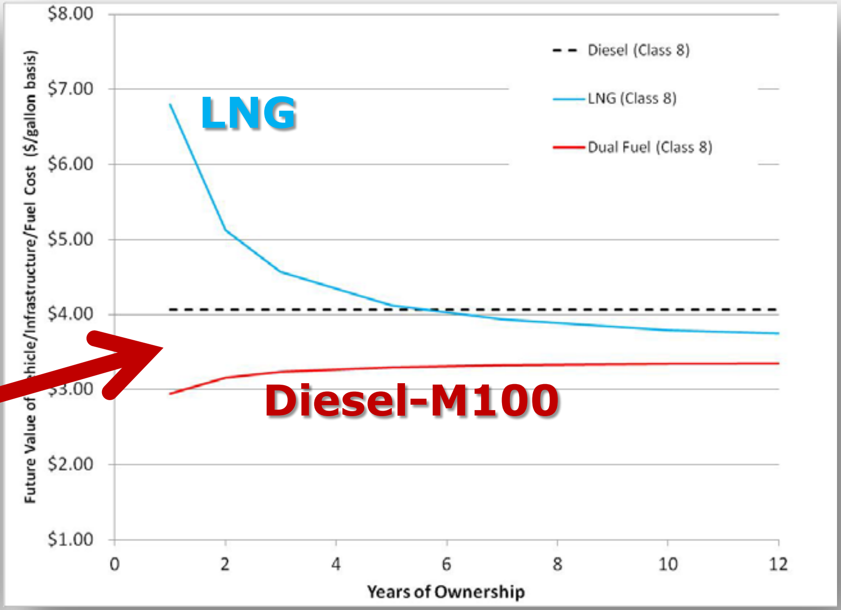
***Cost of Vehicle Operation* versus *Years of Ownership*: Class 8 Truck**

Projected 2017 price levels
(based on EIA's 2012 AEO Report)



*(Assumes 50 vehicles, 200k miles per year; EIA projection for 2017 yield NG commodity prices at **4.76/MMBTU**)*

Projected 2017 price levels
(based on historic NG price levels)



*(Assumes 50 vehicles, 200k miles per year; historic NG pricing for 2017 yields NG commodity prices at **$9.26/MMBTU**)*

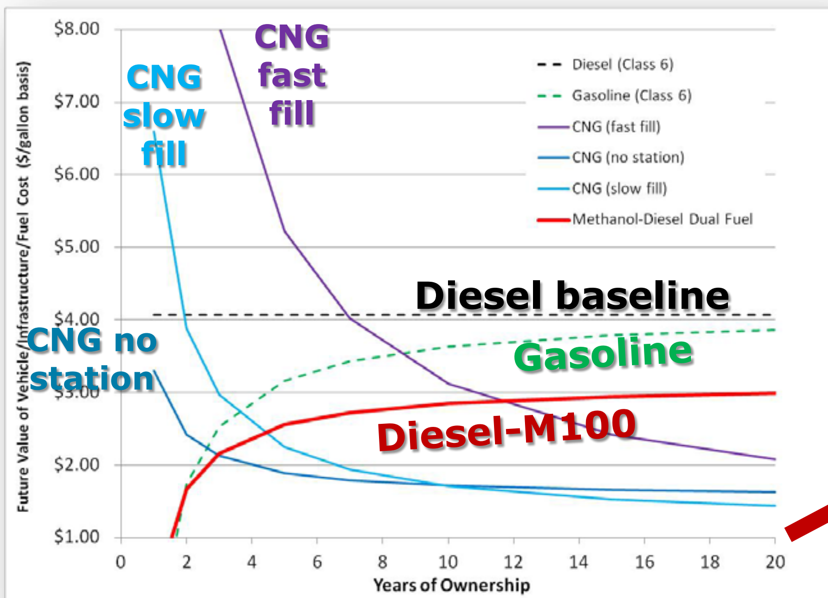
Estimating Operating Costs

Dual Fuel Methanol-Diesel versus CNG

Cost of Vehicle Operation* versus *Years of Ownership*:** ***Class 6 Delivery Truck

Projected 2017 price levels

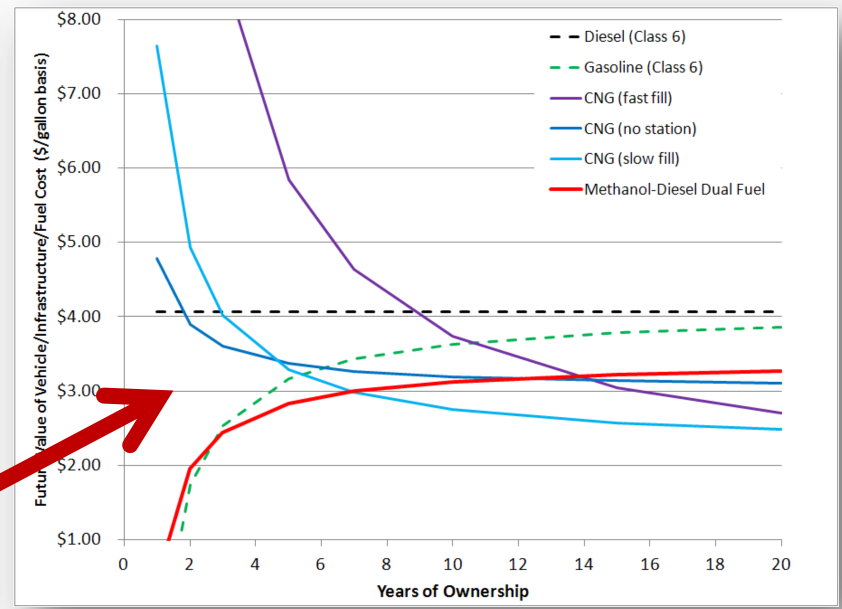
(based on EIA's 2012 AEO Report)



*(Assumes 50 vehicles, 20k miles per yr; EIA projection for 2017 yields NG commodity prices at **$4.76/MMBTU**)*

Projected 2017 price levels

(based on historic NG price levels)



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Dual-Fuel Engine

Highlights

- Simple adaptation of a conventional diesel
- No SCR needed
- 5% more efficient that conventional diesel
- No engine performance degradation
- Fuel costs are 20-30% less that for all diesel
- Modest cost for methanol fueling equipment
- Deployment can easily begin with centrally fueled fleets

Next Development Steps

Vehicle Demonstrations

- Class 6 UPS truck evaluation – Fall 2012
- Potential for a pilot program of 10-20 class 6 & 8 vehicles

Continued refinement of dual-fuel technology

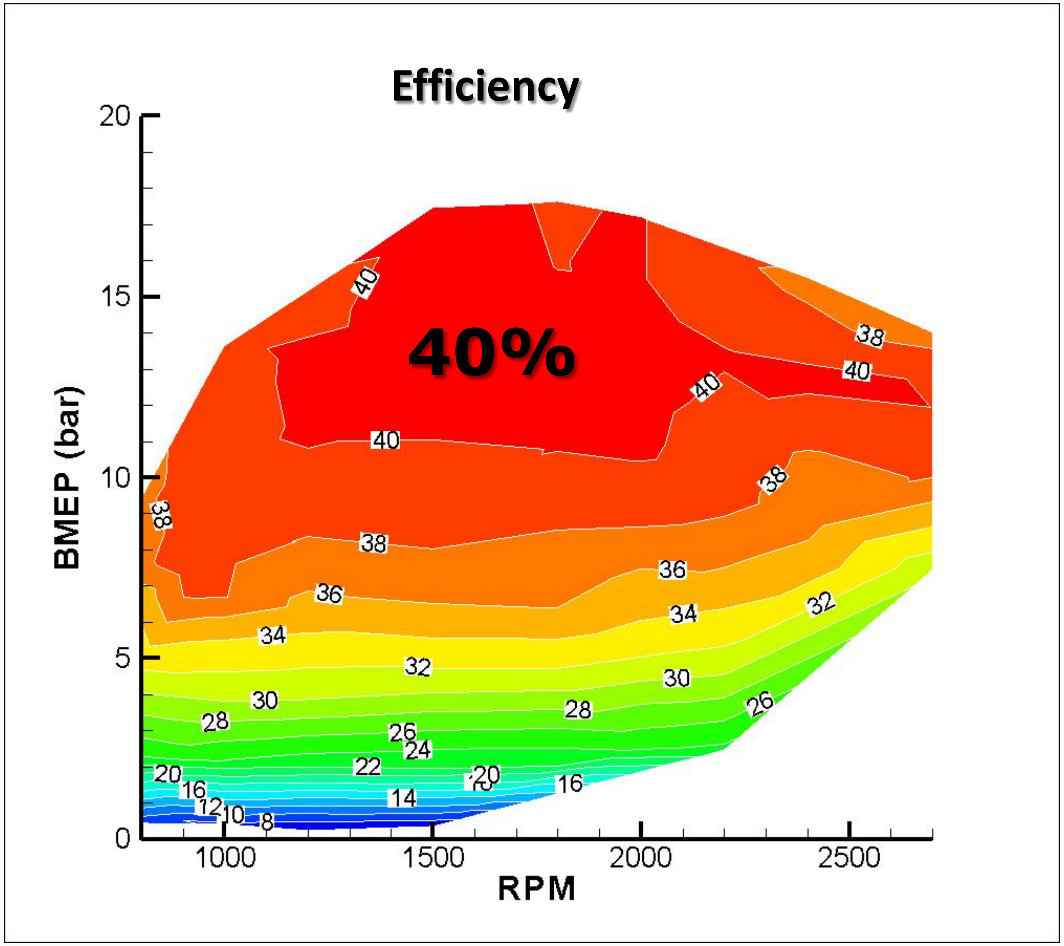
- Refine engine calibration and engine fuel injection system to maximize methanol consumption
  - Optimize engine control strategy for transient performance
- Optimize turbomachinery, fuel injection systems, combustion chamber, EGR system, etc.
- Extend application to less-expensive fuels (e.g., "crude" M100)

Thank You

The remaining slides contain reference information about EPA's dual-fuel engine.

Dedicated Alcohol Spark Ignition Engine

(calibrated for M85)



- ✓ Diesel-like efficiency at a cost similar to a turbocharged gasoline engine
- ✓ Potential cold start, durability issues — engineering solutions exist

Engine Platforms for EPA's Alcohol Research

	Dedicated M85 Spark Ignition	Dual Fuel (Diesel/M100)
Base Engine Test Platform	Navistar VT-275	Navistar 4.8L
Configuration	6 cyl, 60-degree V	4 cyl, inline
Displacement	4.5 liters	4.8 liters
Bore x Stroke	95mm x 105mm	105mm x 137mm
Compression Ratio	16.3:1 (base diesel = 18:1)	16.8:1
Max. power	140 kW @ 2200 rpm	143 kW @ 2200 rpm
Valvetrain	4 valve/cyl, overhead valve	4 valve/cyl, overhead valve
Fuel Injectors	PFI, 2 per cyl	PFI (2/cyl); HPCR/1800 bar
Fuel Type	M85	M100/Diesel
Ignition System	Spark Ignition (CDI)	(None)
Air Induction System	Twin VGT	VGT
Engine Control Module	Pre-production controller	Pre-production controller
Exhaust Aftertreatment	Three-way catalyst	DOC

Comparison of General Features

	Dedicated M85 Spark Ignition	Dual Fuel (Diesel-M100)
Refueling	Transparent to user	Special refueling procedures
Cold starting	Fuel additives or charge air heating	Diesel: glow plug
Oil dilution	High	Moderate
Fuel - alcohol content/ quality tolerance	Moderate/fair	High
Limp home capability	De-rated operating range with lower octane fuels	Diesel only operation, limited range
Bottoming cycle compatibility	Cold starting requires10-15% gasoline, reducing possibility for effective exhaust heat reforming	M100 as primary fuel, suitable for exhaust heat reforming

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Engine Hardware Comparison

	Dedicated M85 Spark Ignition	Dual Fuel (Diesel-M100)
Cylinder Head	Modified for spark plug	No change from stock
Combustion Chamber	Pistons modified for lower CR	No change from stock
Intake Manifold	Modified for port fuel injectors (PFI)	Modified for port fuel injectors (PFI)
Fuel system	4 bar PFI or 150 bar DI	4 bar PFI and 2000 bar DI
Ignition type	High-energy SI	No change from stock
Aftertreatment	TWC	DOC
EGR system	LP cooled EGR	Dual loop cooled EGR
Air induction system	Single-stage VGT with high-capacity aftercooler	No change from stock

Engine Combustion Comparison

	Dedicated M85 Spark Ignition	Dual Fuel (Diesel-M100)
Maximum load	18-20 bar BMEP	16-18 bar BMEP
EGR levels	up to 20%	up to 40-50%
Max. boost requirement	2 bar-abs	2.4 bar-abs
Peak cylinder pressures	130 bar	180 bar
MRPR (bar/deg)	3-5 bar/deg	10-12 bar/deg

Class 6

Dual-Fuel Diesel-Methanol vs. CNG

*Vehicle Costs**

CNG	Diesel-Methanol
Hardware added: • Spark ignition system • CNG gaseous fuel injection system • CNG storage tanks and related equipment (125 mi range)	**Hardware added:** • Diesel fuel injection system • Methanol-compatible fuel system and tank • DOC/DPF in place of TWC • Turbo • Cooled EGR system
Estimated add-on cost is **$18,000 - $20,000** more than a gasoline-powered class 6 truck*	Estimated add-on cost is **$6,000** more than a gasoline-powered class 6 truck*

** A diesel engine for a class 6 truck is estimated at $14,000 higher than gasoline.*

Comparison of Natural Gas-Based Fuels

Methanol vs. CNG/LNG

CNG "Fast Fill"	LNG	Methanol
• Gaseous fuel, 3600 psi • Training required	• Cryogenic liquid, 3600 psi • Training required	• Liquid fuel, conventional filling nozzle • Minimal training required for safe handling and dispensing
• High heat gain during fast fueling results in 30+% loss of vehicle range	• High heat gain during fast fueling results in 30+% loss of vehicle range	• n/a
• Industrial utility services ○ 8 inch NG service ○ Electrical demand • High capital cost (>$2M)	• Industrial utility services ○ 8 inch NG service ○ Electrical demand • High capital cost (>$2M)	• In-ground or above-ground tanks • Modest cost ($30-$55k)

Dual-Fuel Engine Team

National Vehicle & Fuel Emissions Laboratory
U. S. Environmental Protection Agency

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- Michael Prince
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