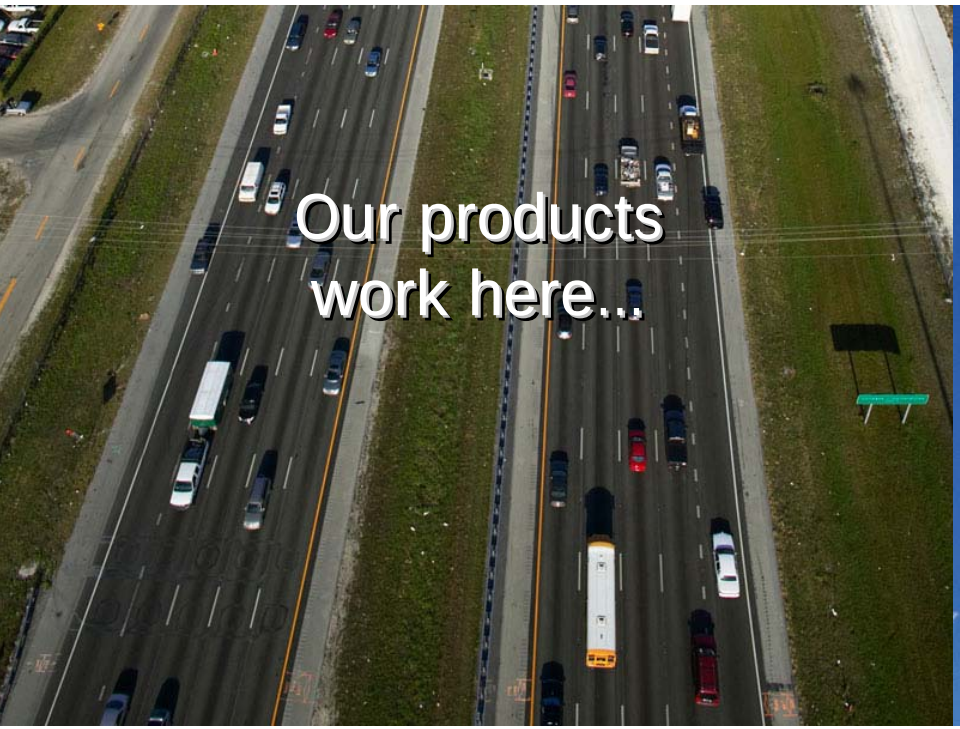


Emerging developments in heavy duty natural gas engines

Patric Ouellette, C.T.O.

October 2011

IGRC Seoul 2011
International Gas Union Research Conference

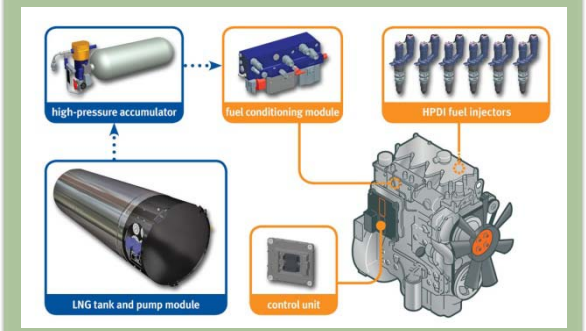
Westport at a Glance

market focus

Transformation from petroleum-fueled to alternative-fueled engines.

position

The global leader in gaseous fuel engineering and technology.



strategy

Leverage IP to penetrate markets through relationships with market-leading OEMs.

Cummins · CAT · GM · DELPHI · KENWORTH · FREIGHTLINER · Peterbilt · HYUNDAI · Mack · Volvo · 潍柴动力 WEICHAI POWER · PACCAR

Leverage Technology Across Broad End-Market Applications

Equivalent or Better Performance Without Need for Petroleum-based Fuels

Differentiated Technology

High-Pressure Direct Injection (HPDI)

Compressed Natural Gas Direct Injection (CNG-DI)

Light-Duty Alternative Fuel Engines & Systems

Medium-Duty Alternative Fuel Engines

Heavy-Duty Westport GX Engines

Cryogenic Natural Gas Storage & Delivery

All classes of the vehicle market

Light-Duty (1-5 litres)

Juniper Engines Inc.

Medium-Duty (5.6-9 litres)

Cummins Westport

Heavy-Duty (11-16 litres)

High-Horsepower (>16 litres)

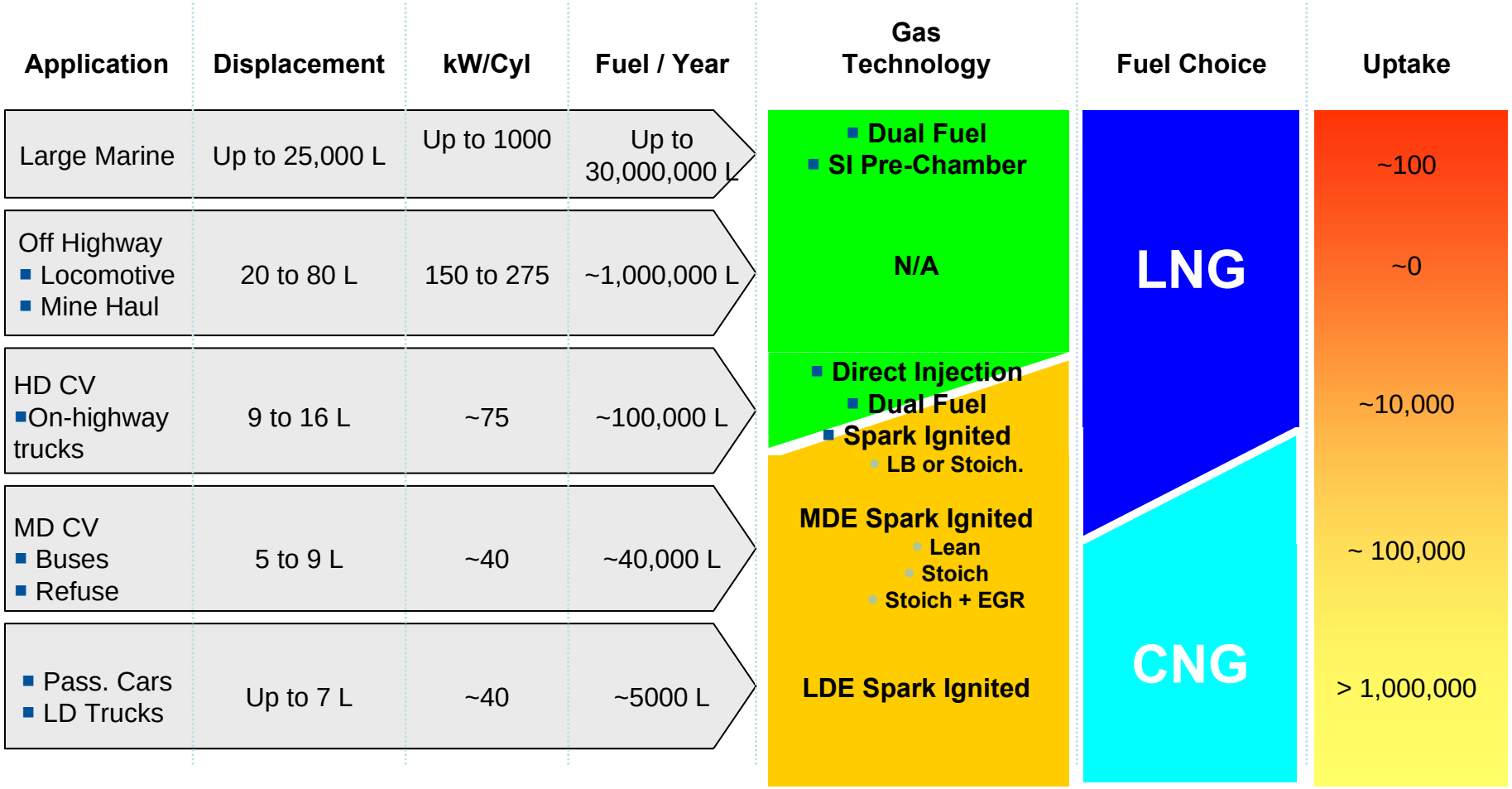
Westport™ HD

Class-leading emissions performance while maintaining equal horsepower, torque, and efficiency to a diesel-fueled engine

Agenda

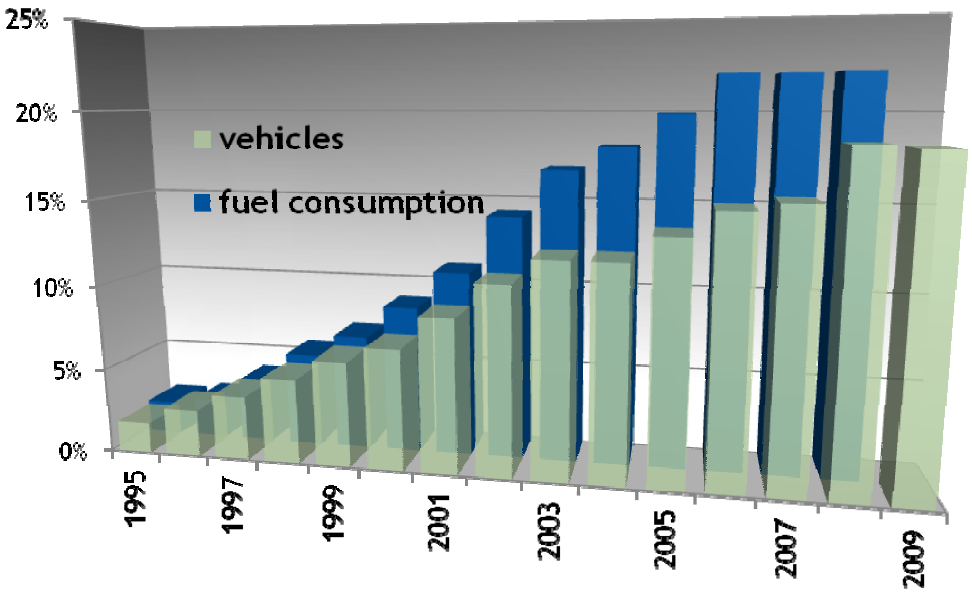
- Today's Technology Spectrum
- Main Technology Drivers by Segments
  - Medium Duty Commercial Vehicles
  - Heavy Duty Commercial Vehicles
  - High HorsePower
- Future Outlook

Technology Spectrum – Mobile Application



Values are coarse estimates and information is based on the author's knowledge - for illustration purposes

Medium Duty Commercial Vehicles
U.S. Transit & Refuse Markets



- U.S. natural gas transit bus population:
  - 18.5% of in-service vehicles
  - 22.1% of fuel consumption

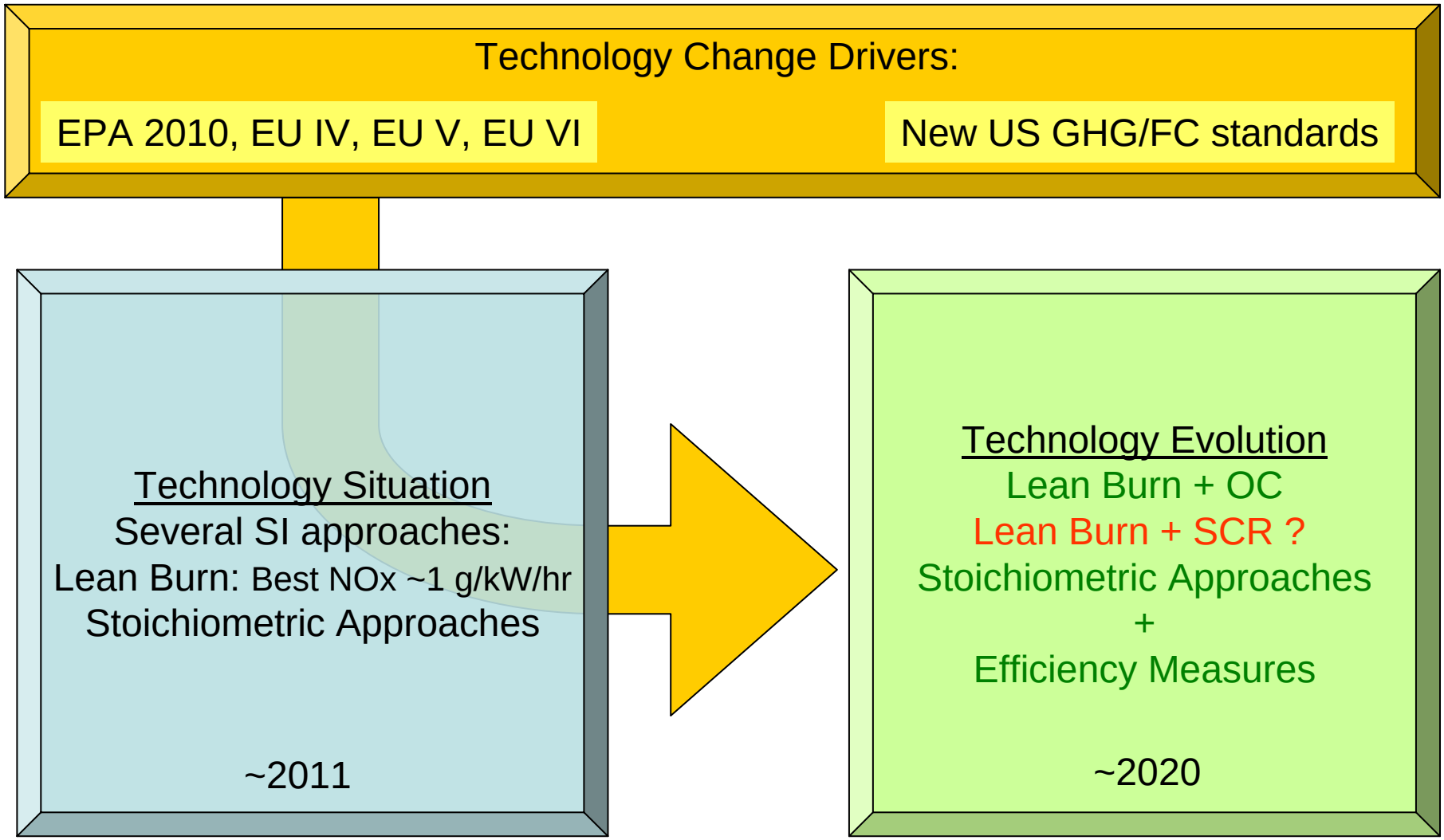
Refuse "Trends" 2011

About 80% of the trucks Waste Management purchases this year will be natural-gas trucks. Including the addition of its new truck Tuesday, Waste Management operates 1,000 natural-gas trucks: 51% run on compressed natural gas, or CNG, 49% on LNG.

—latimesblogs.latimes.com/greenspace/2011/07/waste-management-trash-trucks.html

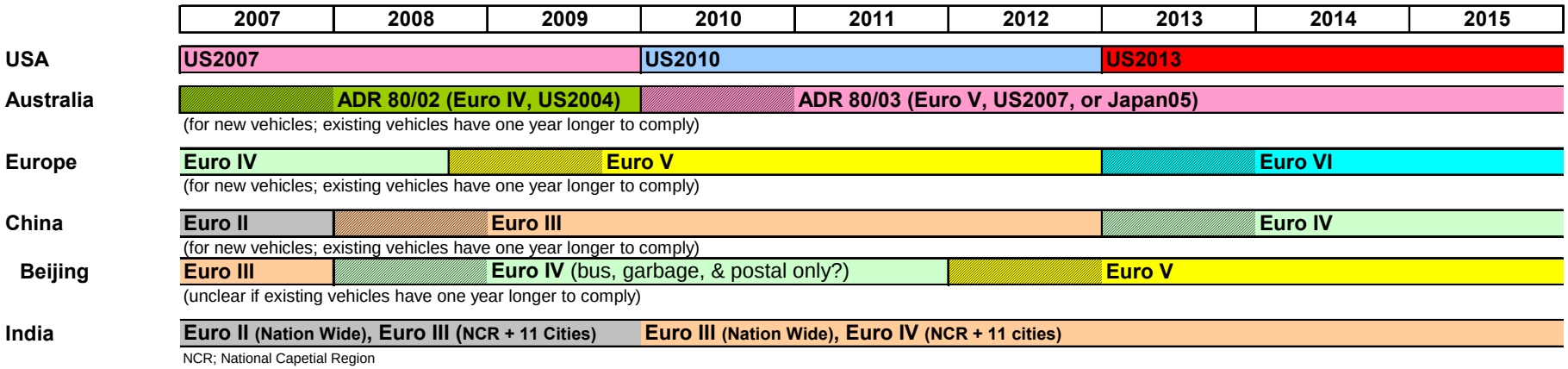
chart source: American Public Transit Association

Medium Duty Commercial Vehicles



Emissions Changes

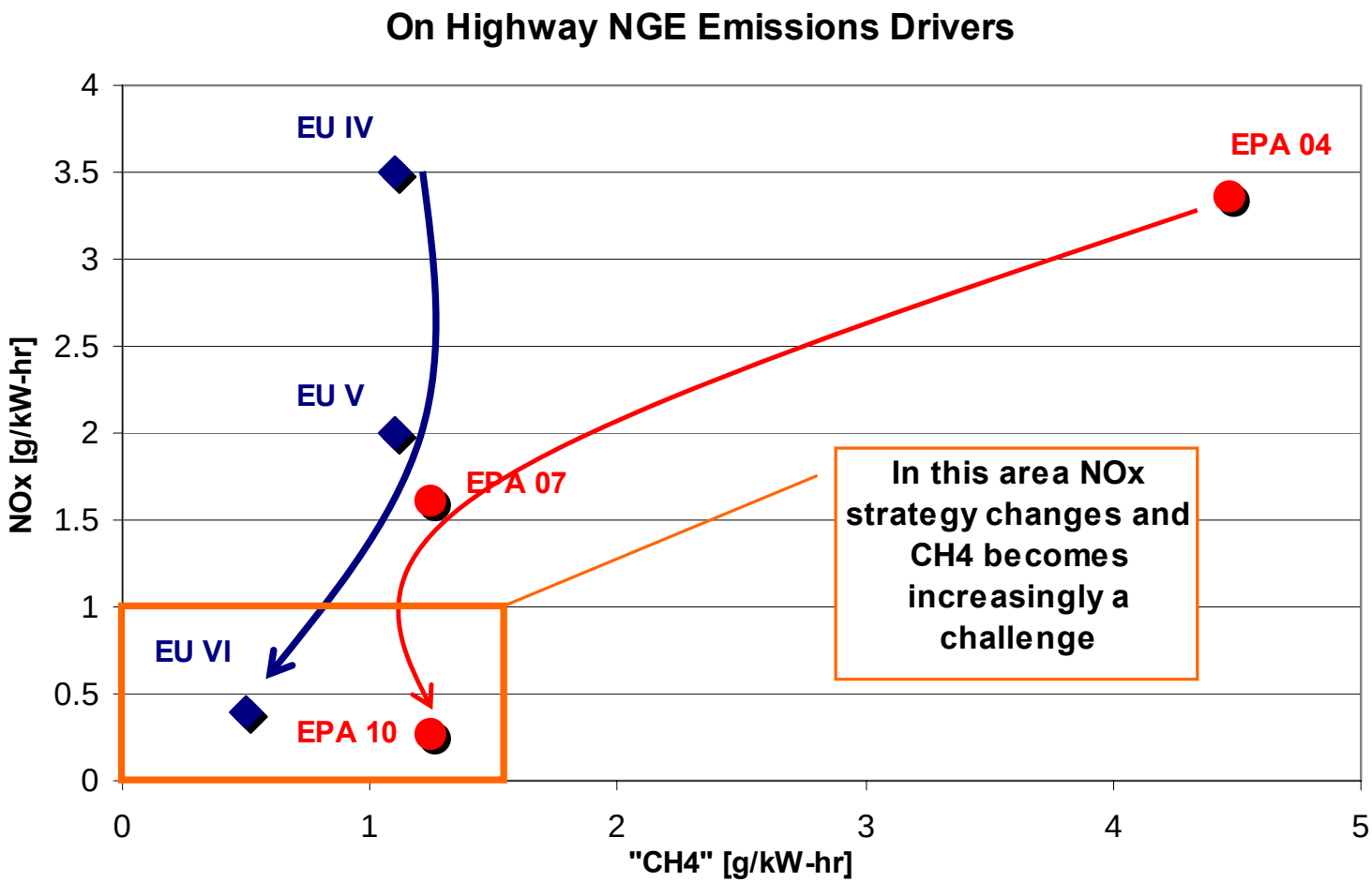
World Emissions Standards for On-Road Heavy-Duty Truck Engines



data sources: www.dieselnet.com; "Worldwide Emissions Standards, Heavy Duty & Off-Road Vehicles", Delphi, 2009.

- Emission changes have traditionally been catalysts for new technologies.
- Diesel truck prices have increased due to emission changes.
- Presents an opportunity for natural gas engines

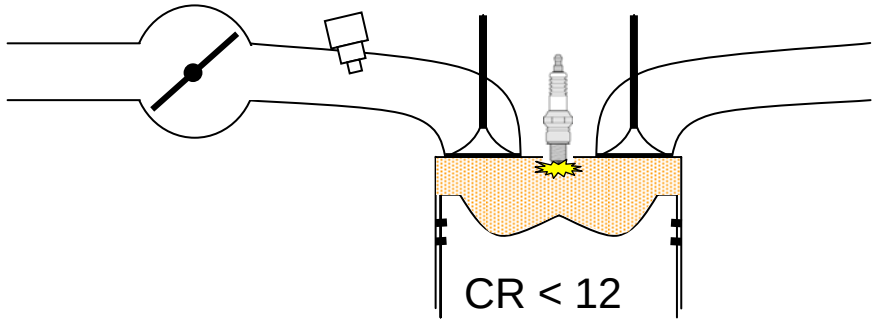
Emissions Changes and NG Engines



While EPA does not mandate CH4 emissions, it is assumed here that nmHC/CH4~0.15

Spark-Ignited Natural Gas Engines

- Many different technology levels
- All throttled
- All fumigated
  - The NG is mixed with intake air before compression
  - Requires throttling to control load while maintaining target A/F ratio
  - Requires reduced compression ratio to avoid knock



For EU VI / EPA 2010

Advantages	Challenges
• Low emissions with simple catalyst • Low noise	• Part load efficiency gap • Reduced torque capability

- **Mixer**
- **Open loop**
- **Stoichiometric**

- **Single Pt Injection**
- **Close Loop**
- **Lean Burn**

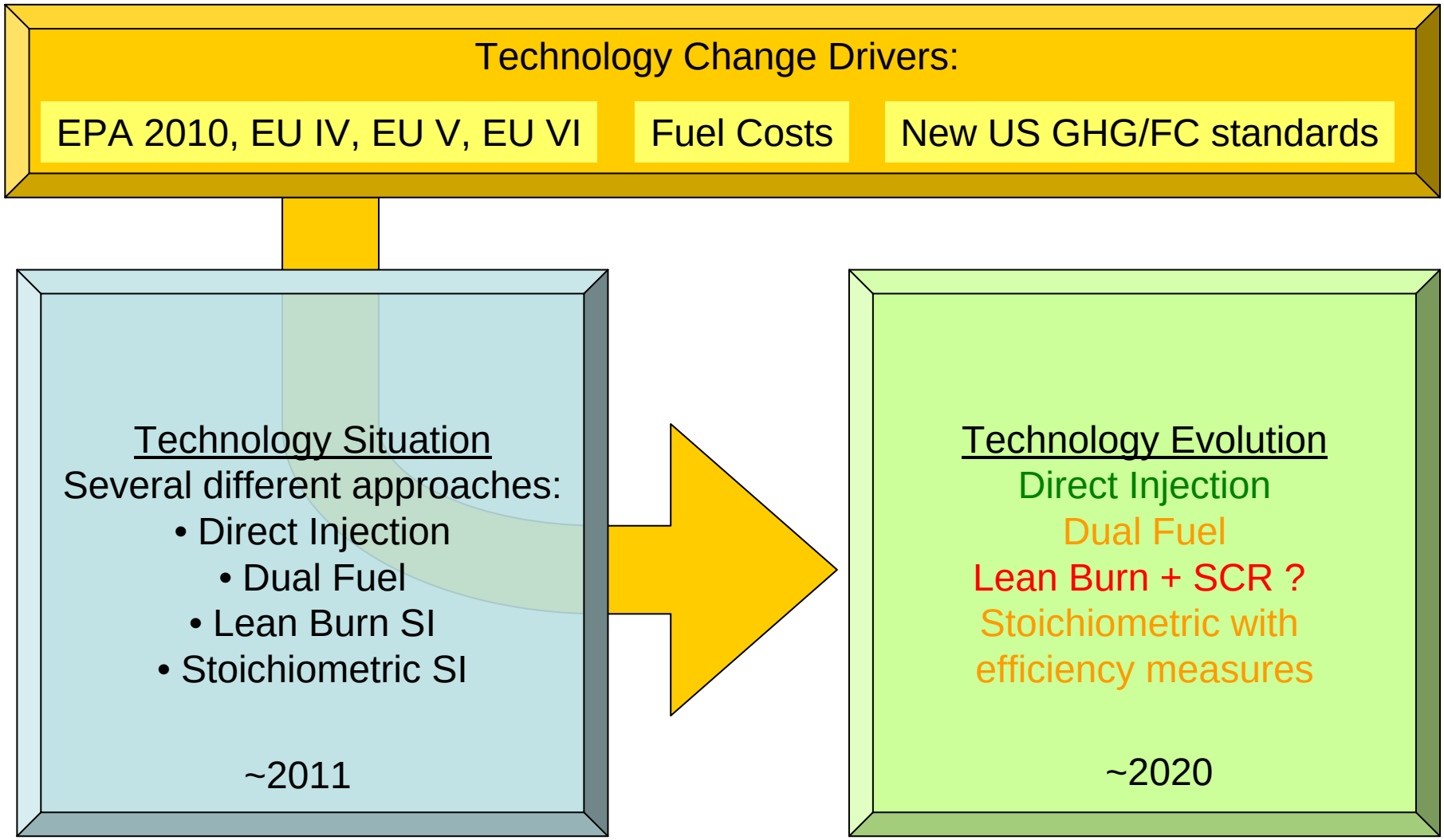
- **Multiple Pt Injection**
- **Close Loop w/ full sensing**
- **Stoichiometric with or w/o EGR**

- **Efficiency Measures**

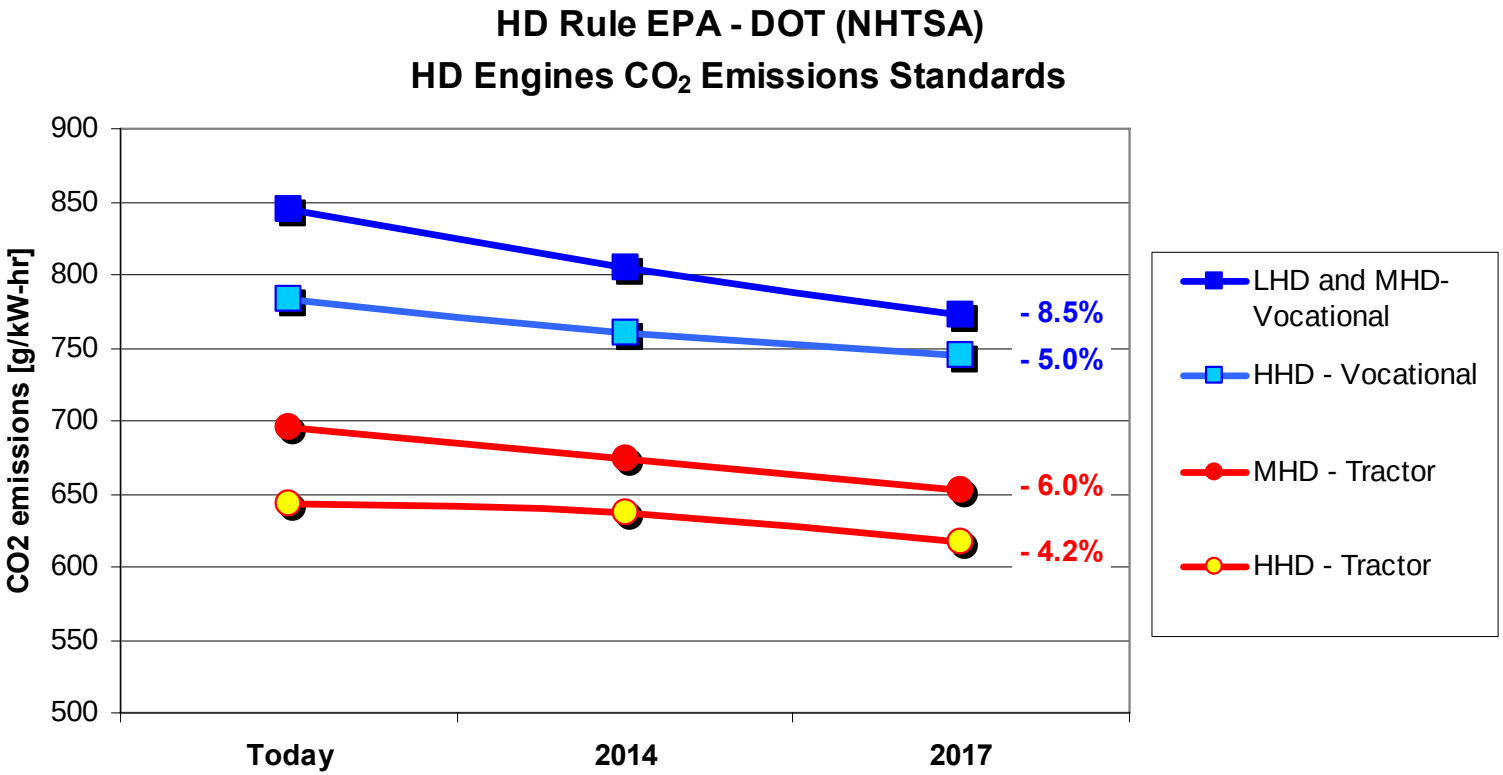
HD Commercial Vehicles
Weichai Westport LNG Engine Application Example

- WWI WP12NG380E40 product is used in coal field, and coal transportation industry, where the working condition is very harsh and over-loading is frequent.
- These are Spark Ignited, Lean Burn
- There is are more than 1000 HD LNG trucks in this segment in China

Heavy Duty Commercial Vehicles



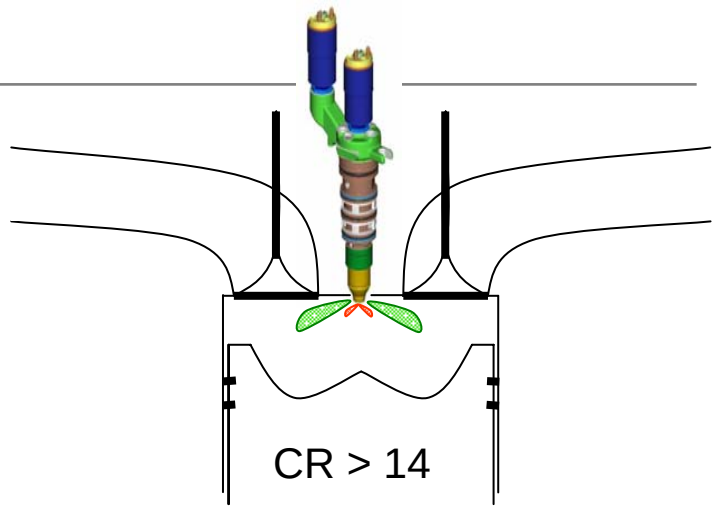
EPA CO2 – NHTSA FC Standards



- CO_2 regulation should benefit NG engines
- Diesel engine efficiency will increase, moving the benchmark for NG engines

Direct Natural Gas Fuel Injection - HPDI

- The NG is directly injected in the combustion chamber, late in compression cycle
- Ignition with pilot diesel fuel
  - <5% is diesel during vehicle operation
- No throttling required
- Not knock limited



For EU VI / EPA 2010

Advantages	Challenges
• Maintain High Efficiency • Maintain High BMEP	• Requires lean NOx catalyst

- **EGR**
- **Oxidation Catalyst**
- **SCR**
- **Particulate Control**
- **Efficiency Measures**

HPDI HD Truck Applications

City Of LA Roll Off Trucks

PG&E Warehouse Trucks

LAX Dump Trucks

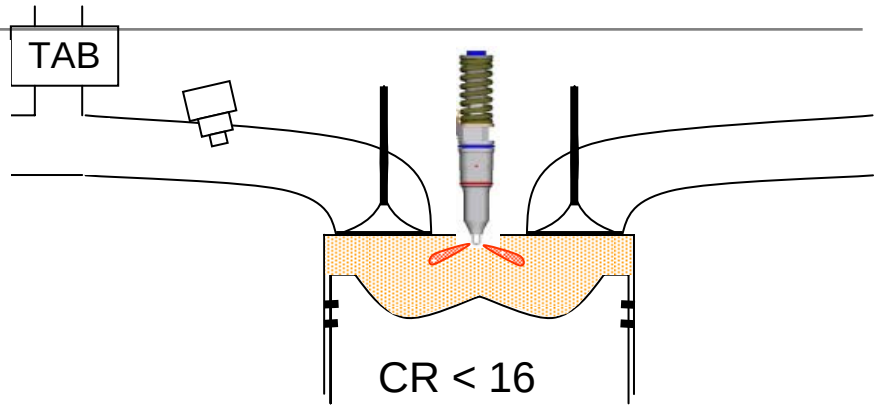
Prometheus Trailer

Kenworth HPDI Truck

LA Sanitation Refuse Transfer

Dual-Fuel Engines

- Different technology levels
- Retains diesel operation capability
- Under NG operation
  - The NG is mixed with intake air before compression
  - Diesel used for ignition of the lean mixture
  - Requires air fuel ratio control to yield significant substitution
  - As load increases, use more diesel to avoid knock
  - As load decreases, reduce air or use more diesel to avoid misfire



For EU VI / EPA 2010

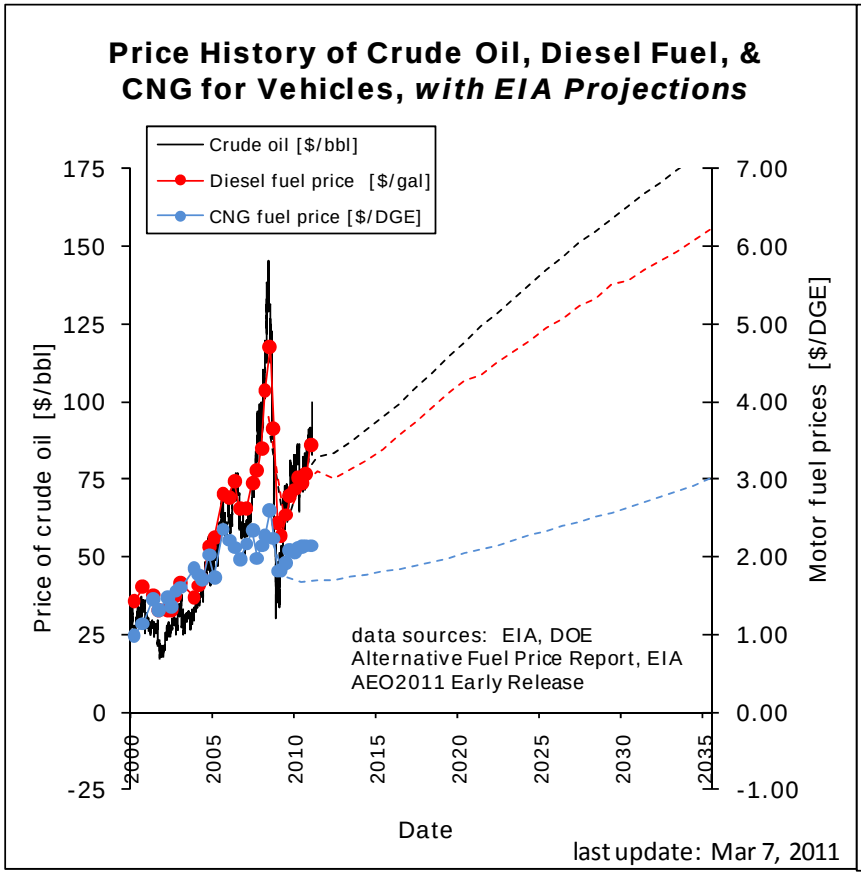
Advantages	Challenges
• Can revert to diesel operation • Maintains good performance	• Requires full diesel after-treatment • Requires full certification under both diesel and gas operation • HC emissions are challenging for Euro 6 • Reduced fuel savings due to diesel operation

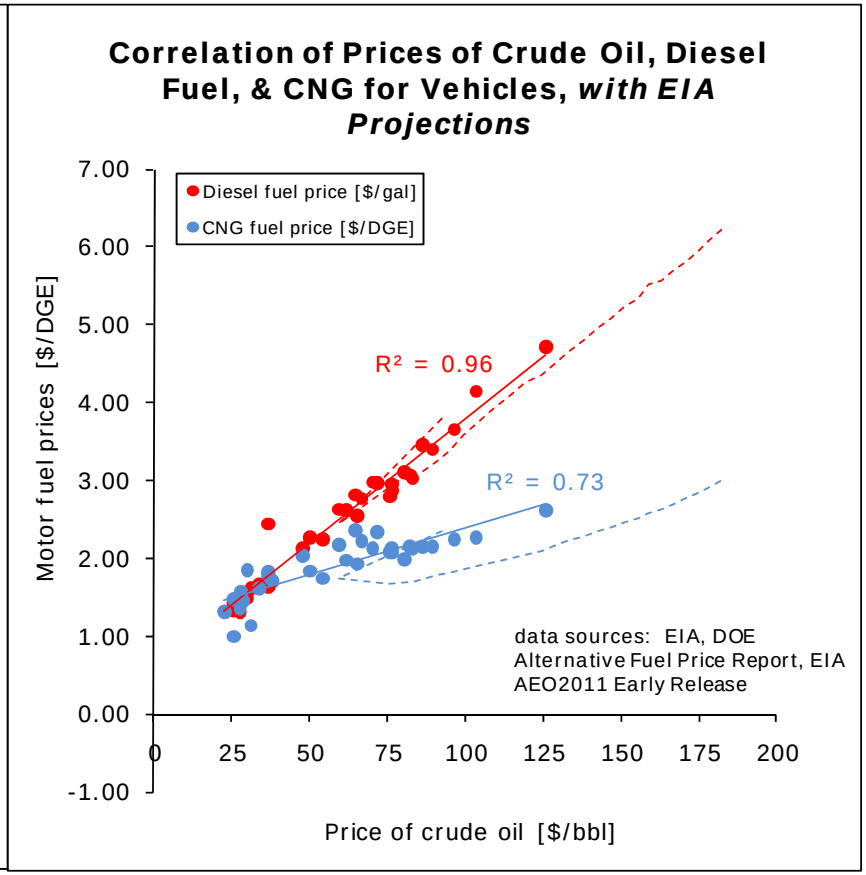
- **Mixer**
- **Open loop**

- **Single Pt Injection**
- **Close Loop**
- **Turbo air by-pass**

- **Multiple Pt Injection**
- **Close Loop w/ full sensing**
- **Throttle**
- **Skip Fire**

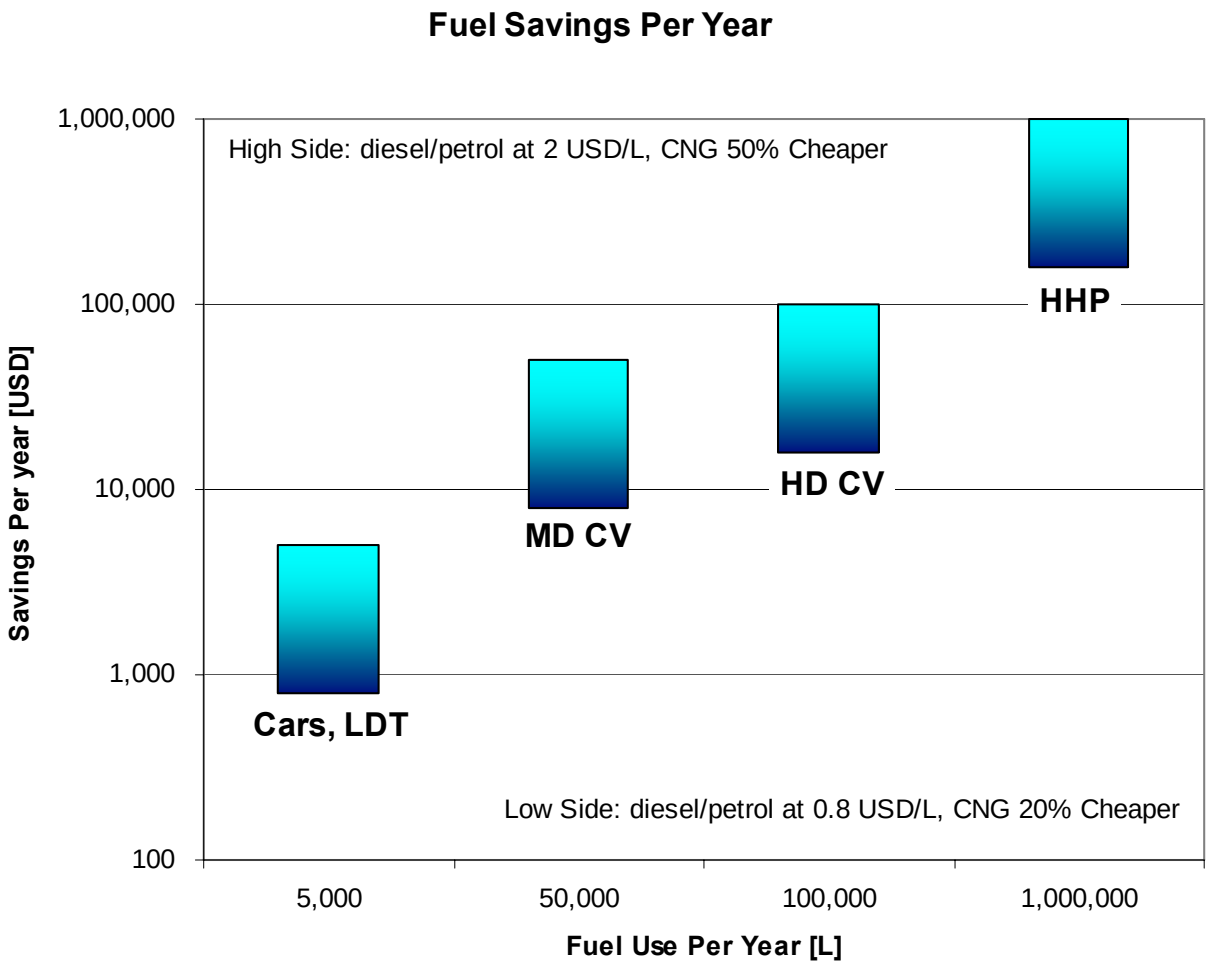
Projections for future prices for crude oil, diesel fuel, and CNG for vehicles in the USA

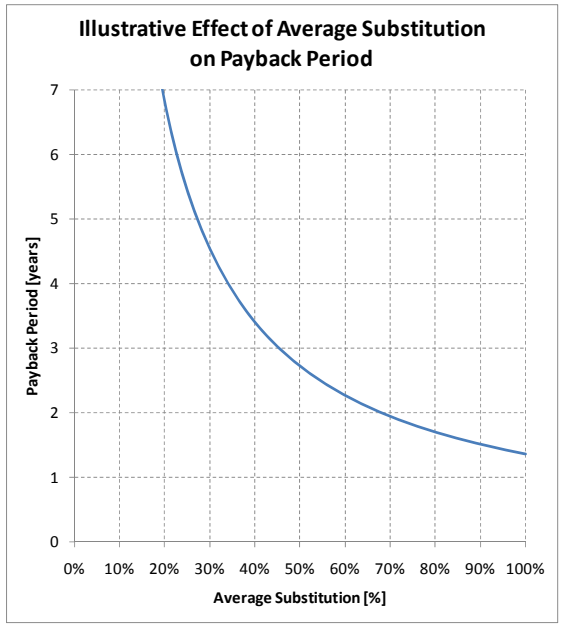




- The EIA's most recent (Dec 2010) projections for future fuel prices show:
  1. The crude oil—diesel fuel relationship will continue
  2. CNG for vehicles will become cheaper than historical trends would predict
  3. Ever-higher prices and an ever-widening diesel-CNG price gap, further strengthening the case for NGVs

Fuel Savings

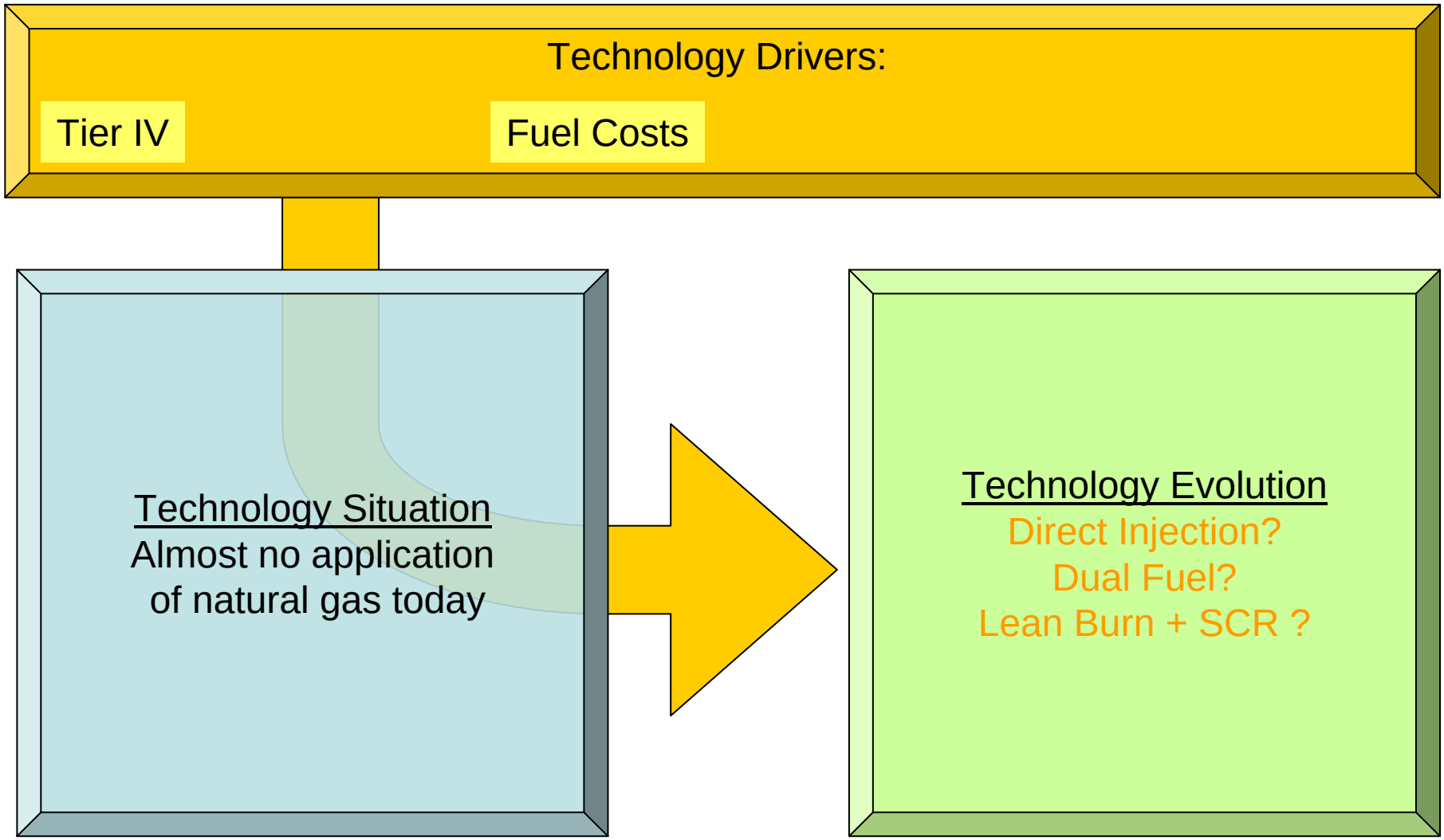




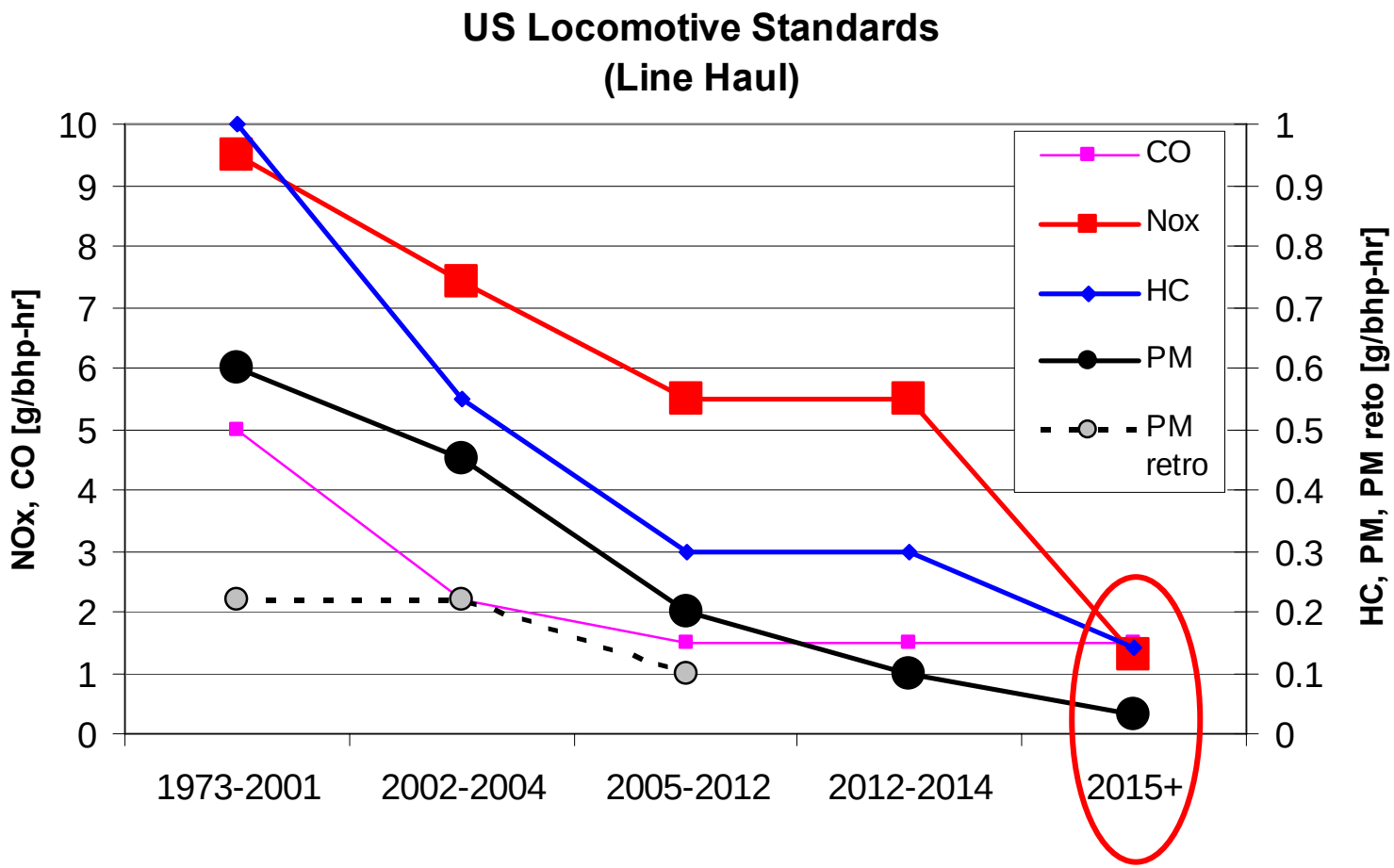
Under Dual Fuel, payback period increases as actual substitution decreases

Values are coarse estimates for illustration purposes

High Horsepower Vehicles



Locomotive Tier IV Standards



Meant to be met using after-treatment

Significant High-Horsepower Opportunities

RESOURCE EXTRACTION INDUSTRY

- $45.4Bn world mining equipment industry [1]
- 2,035 onshore drilling rigs working in U.S. and Canada (U.S. increased from 968 in 2009 to 1,640 in 2010) [2]
- Remote mining and drilling sites make use of conventional fuel expensive

MAN, SANDVIK, KOMATSU, mtu, CATERPILLAR®

target vehicles | current issues | key vendors

- Rail carries more than 40% of U.S. freight [3]
- Fuel represents approximately 24% of the operating costs of railroads [4]
- Most locomotives are diesel-powered, and rail operators need solutions to reduce risk of price volatility of diesel fuel

ELECTRO-MOTIVE, GE, Cummins, MITSUBISHI, ALCO, Waukesha

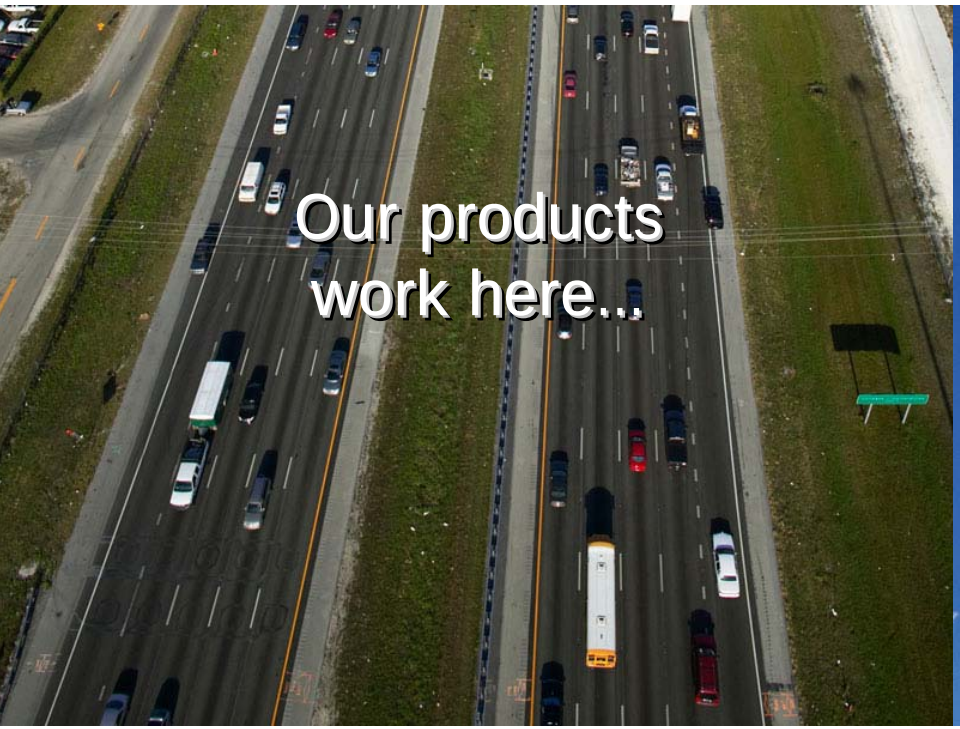
INDUSTRIAL TRANSPORTATION

1) Freedonia World Mining Equipment report, November 2009.
2) Baker Hughes report, August 2010.
3) Burlington Northern 2008 Annual Report.
4) Average fuel costs as percentage of all operating expenses for Union Pacific of 22%, 24% and 25% for CY2009, CY2008 and CY2007, respectively.

Technology Outlook

Over the coming years, we would expect:

- Migration of lean burn spark ignition engines to stoichiometric approaches and adoption of engine efficiency improvement measures in the MD commercial vehicle sector
- Increased deployment of natural gas engines in HD commercial vehicles
  - Increased deployment of direct injection approach
  - Some deployment of dual fuel approaches in situations where infrastructure cannot be well coordinated
- Increased development and demonstration of natural gas in off-highway mobile equipment
  - Technology direction is not settled in these applications, several approaches will likely be tried
  - Direct Injection has the right attributes
- Increased interest of natural gas for marine applications
  - There are some early technology approaches, but applications are very diverse
  - There will likely be experimentation with different technologies for different applications



Thank You

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