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Mobile natural gas engine oil: path towards a sustainable future

Teri Crosby
Global Automotive Engine Oil Manager
April 2018

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Presentation outline

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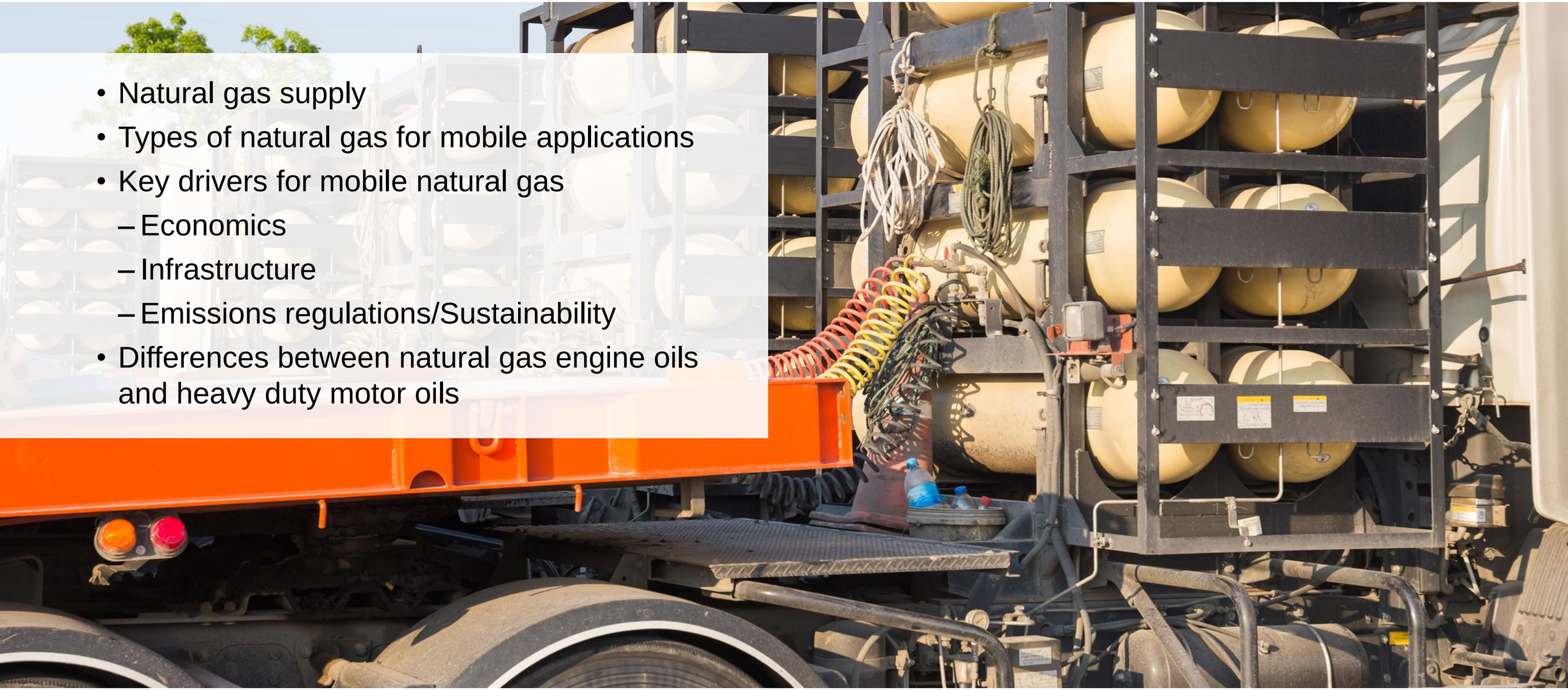

- Natural gas supply
- Types of natural gas for mobile applications
- Key drivers for mobile natural gas
  - Economics
  - Infrastructure
  - Emissions regulations/Sustainability
- Differences between natural gas engine oils and heavy duty motor oils

Major natural gas supply is coming on-line

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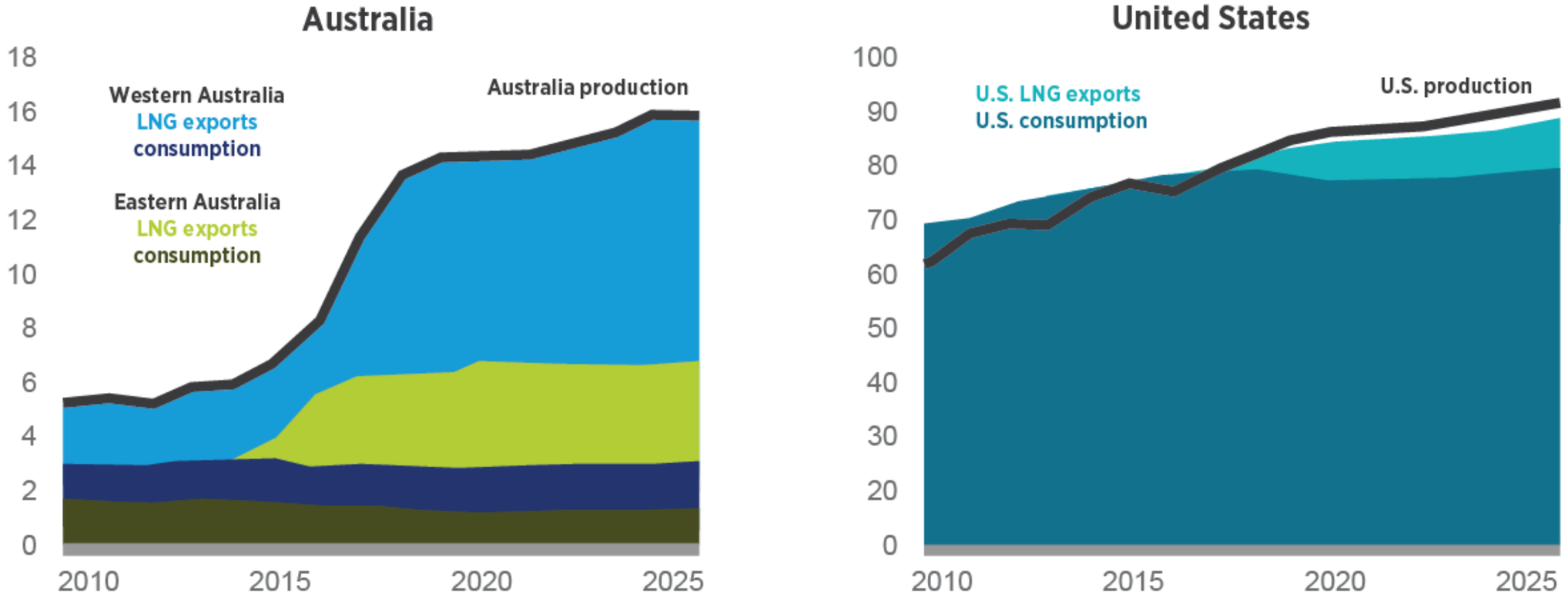
Natural gas production, consumption, and liquefied natural gas exports (2010–2025)

Billion cubic feet per day



Australia is well positioned to meet much of Asia Pacific Region gas needs.
The U.S. has surplus and is starting to export excess production

Source: U.S. Energy Information Administration 2017

Unconventional gas “boom” due to advances in technology – hydraulic fracturing

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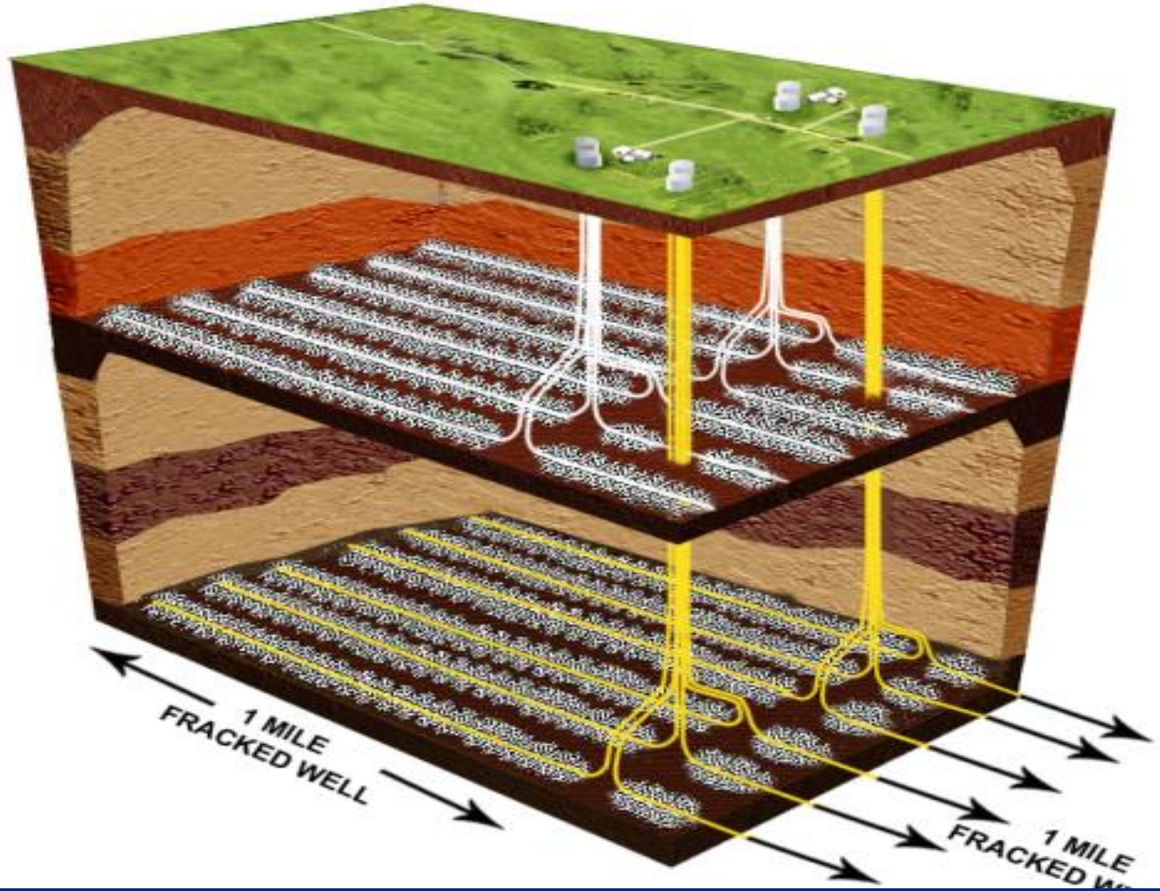

Fracking has led to significant increases in oil and gas production

U.S. natural gas supply
Trend projections

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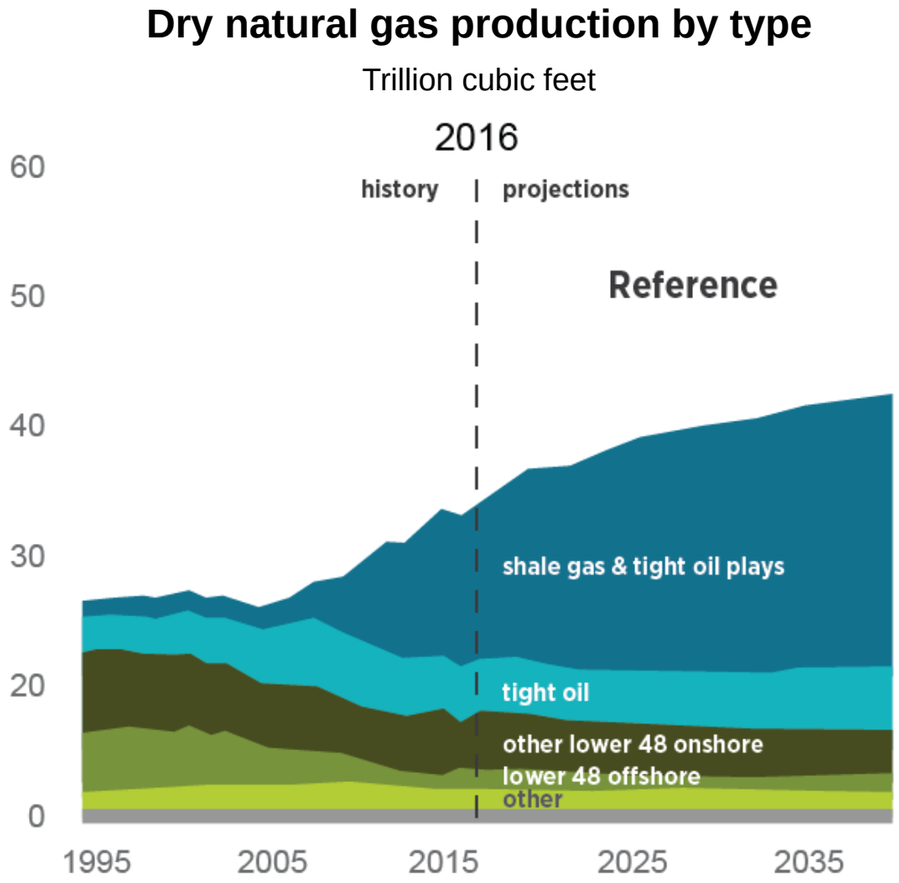

- Shale gas / Unconventional gas has led to abundant supplies of natural gas
  - Horizontal drilling
  - Hydraulic fracturing
- Gas field production can quickly be adjusted as demand and prices vary

Increase in North America supply largely driven by fracking

Source: U.S. Energy Information Administration
http://www.eia.doe.gov/forecasts/aeo/executive_summary.cfm

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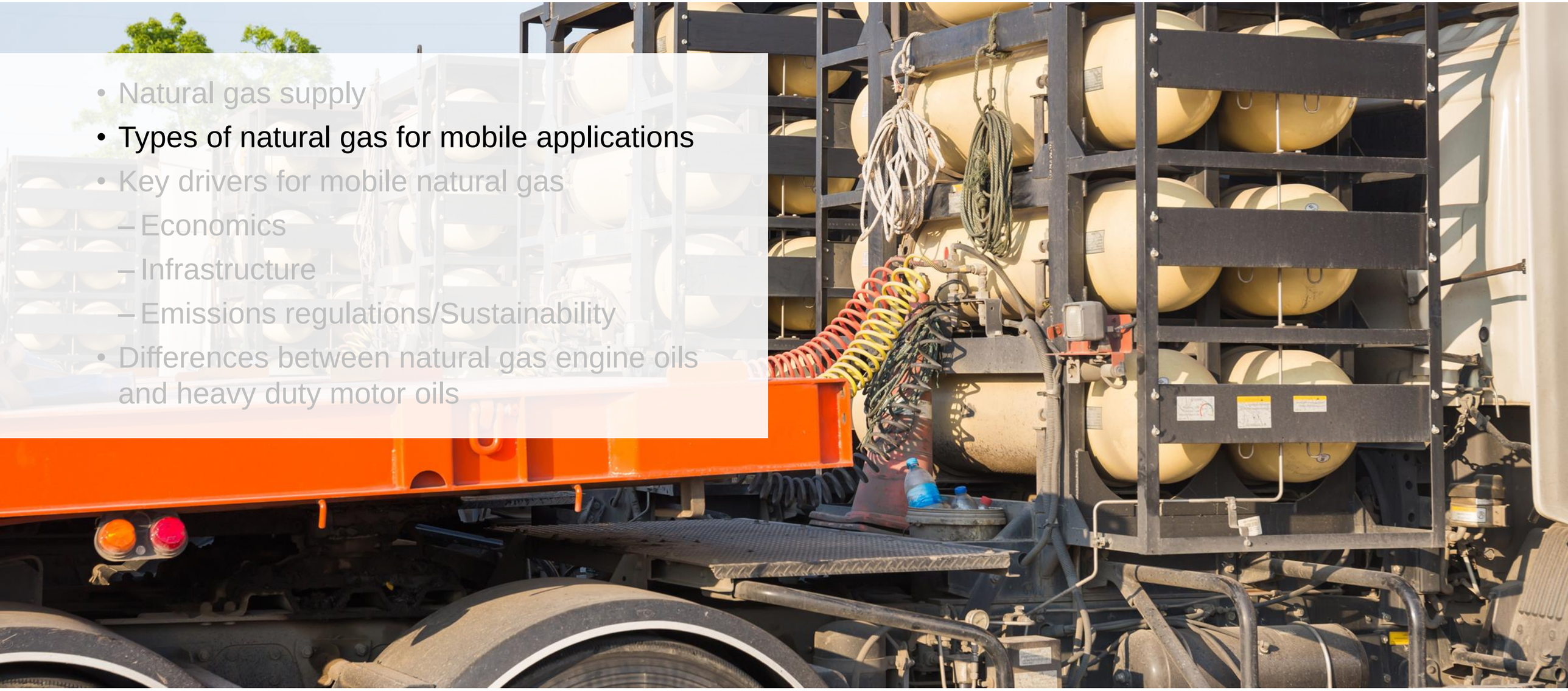

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Natural gas for transportation CNG and LNG

Compressed Natural Gas (CNG)

- Typically delivered to the fueling station site via the local gas utility underground pipe system at low pressure
- Compressed directly to vehicle's onboard storage cylinders at 3600 psi

Liquefied Natural Gas (LNG)

- Cryogenically cooled to liquid state ~-260 deg F @ 40 to 120 psi
- Stored in liquid form onboard vehicle and vaporized before it enters engine cylinder
- Fuel boils off from vehicle tanks if not used

Biomass is used in some cases to produce Renewable Natural Gas (RNG)

Renewable Natural Gas (RNG)

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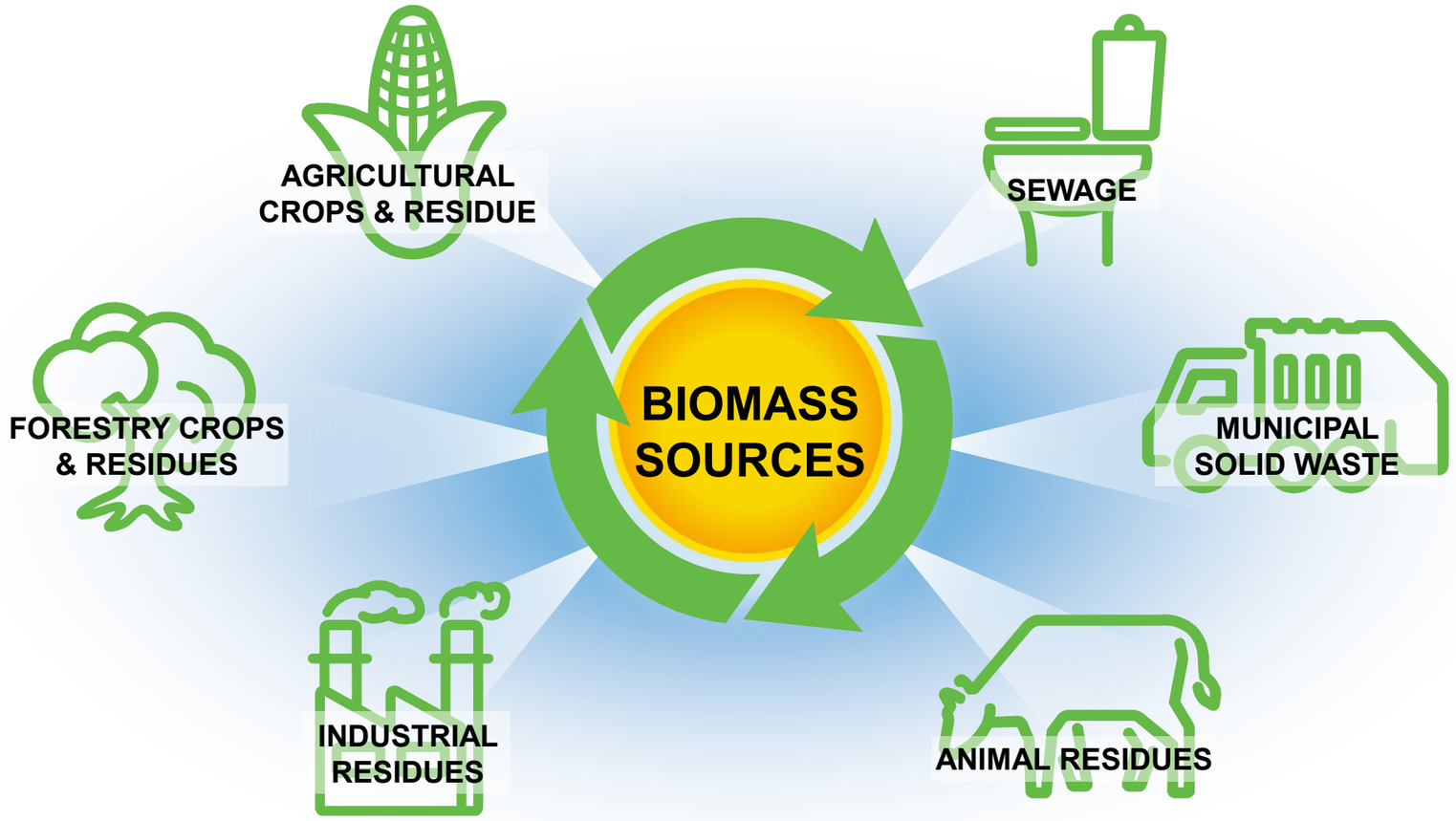
- Reduces greenhouse gas emissions up to 85% on a total life-cycle-analysis (well-to-wheels)
- Can be used in similar applications as CNG or LNG



Data Source: The Coalition for Renewable Natural Gas

Natural gas range and volume comparison

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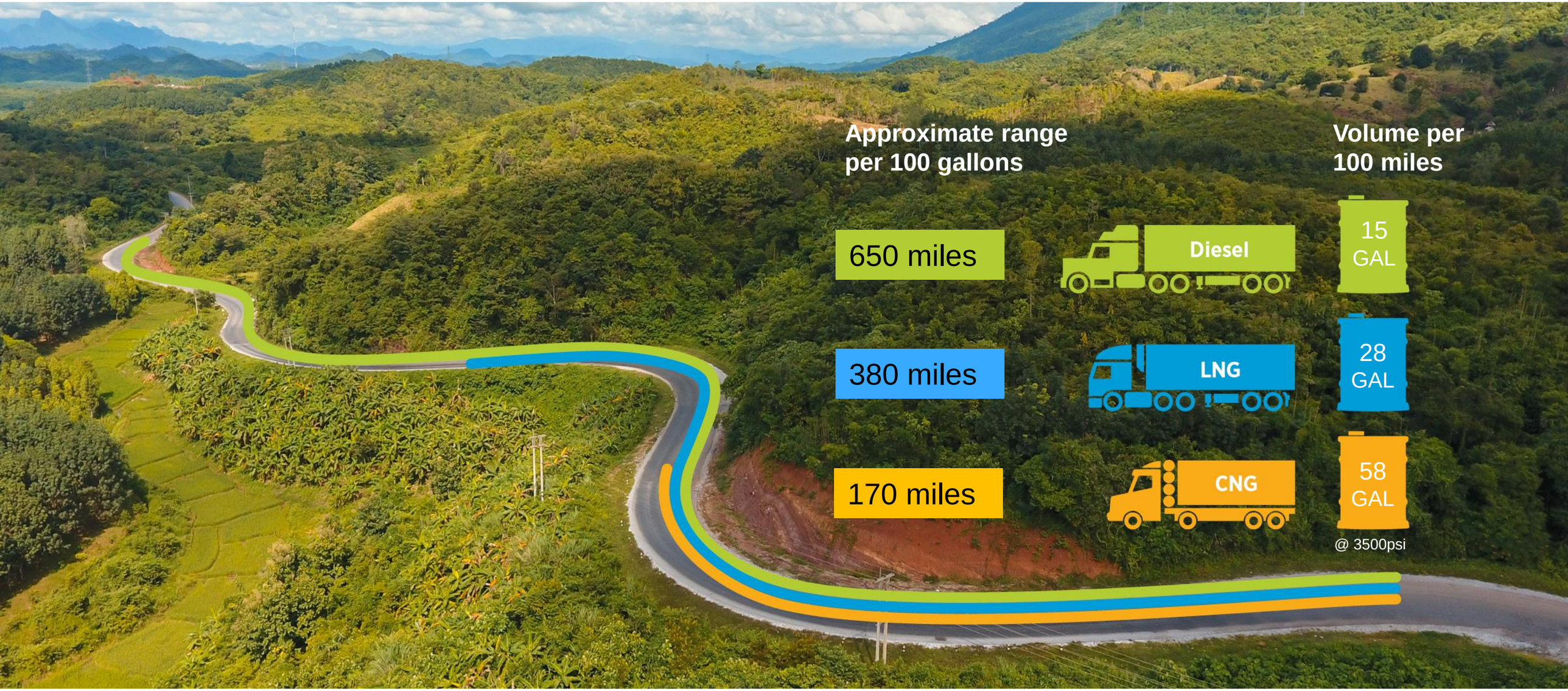

Typical CNG vehicles operated in U.S.

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- Centrally fueled
- Fixed routes
- Low emissions and odor
- Low noise
- Can operate on Renewable Natural Gas (RNG)

Typical LNG vehicles operated in U.S.

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- Used in long-haul applications
- Longer range than CNG trucks
- Low emissions
- Low noise

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New production technologies have resulted in abundant supply of natural gas and low, stable prices

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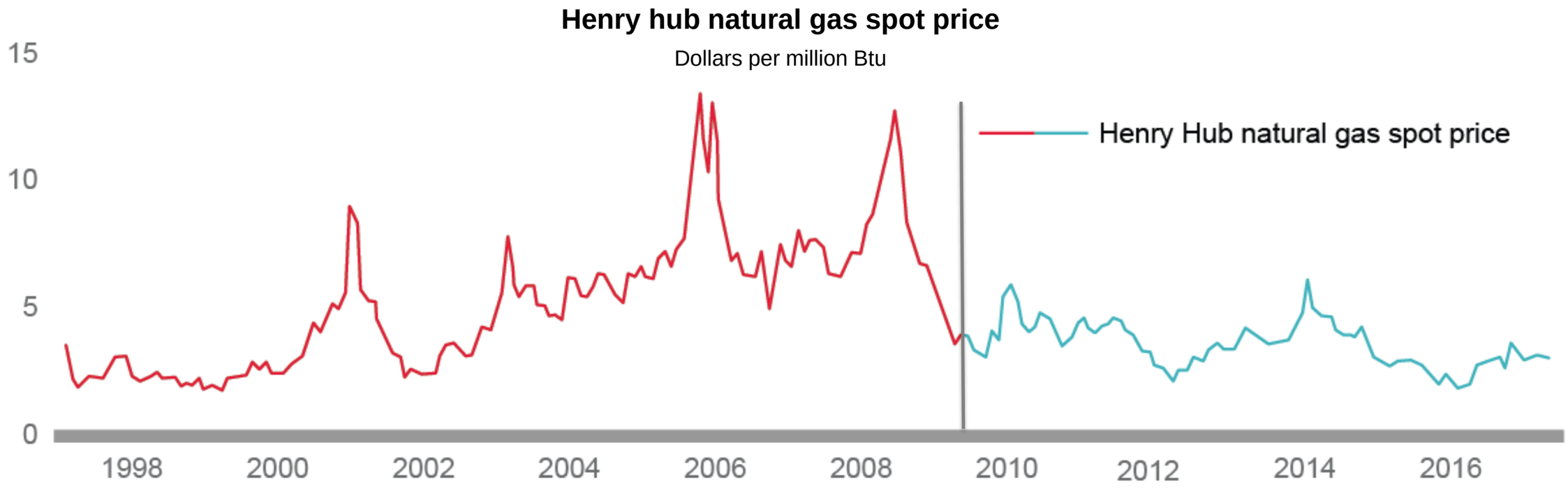
Volatile natural gas prices

Stable natural gas prices



Fleets were not willing to invest in natural gas trucks in the past, in part due to volatile prices

Source: U.S. Energy Information Administration

Natural gas market is becoming more global wide price disparities are disappearing

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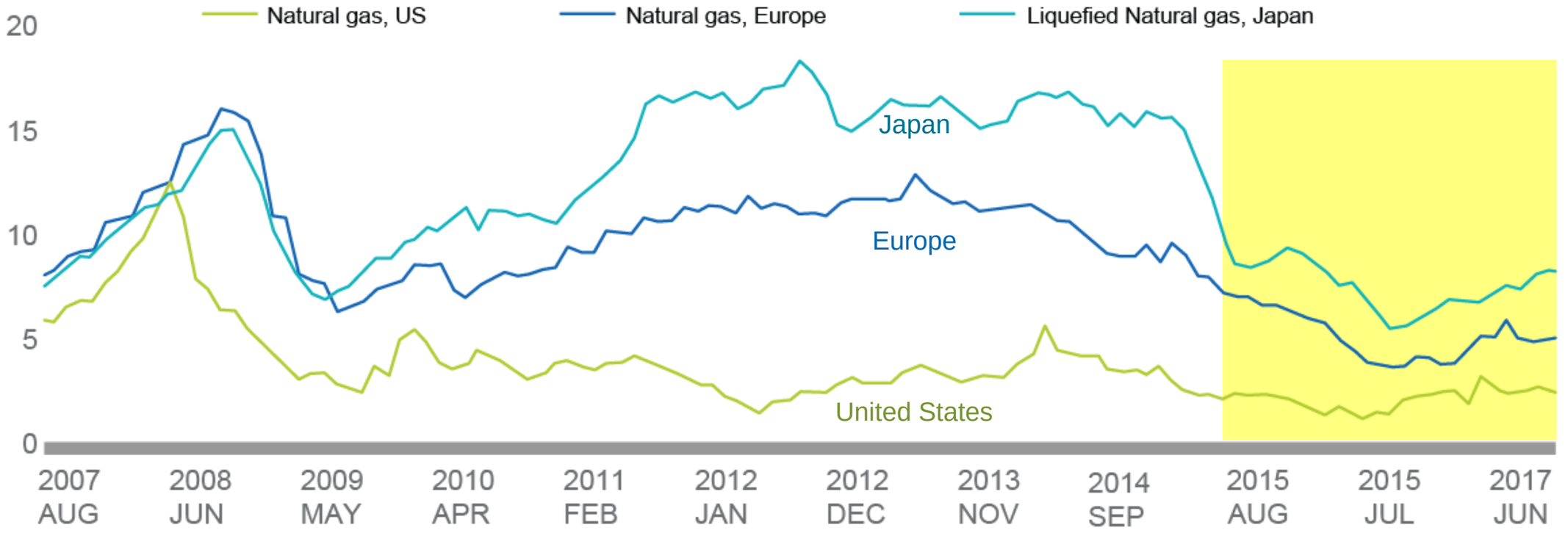
Monthly spot natural gas prices

nominal U.S. dollars ($/mmbtu)



Regional price gaps are narrowing as U.S. and Australia increase exports

Source: U.S. Energy Information Administration

Natural gas prices are forecasted to remain low regional differentials remain

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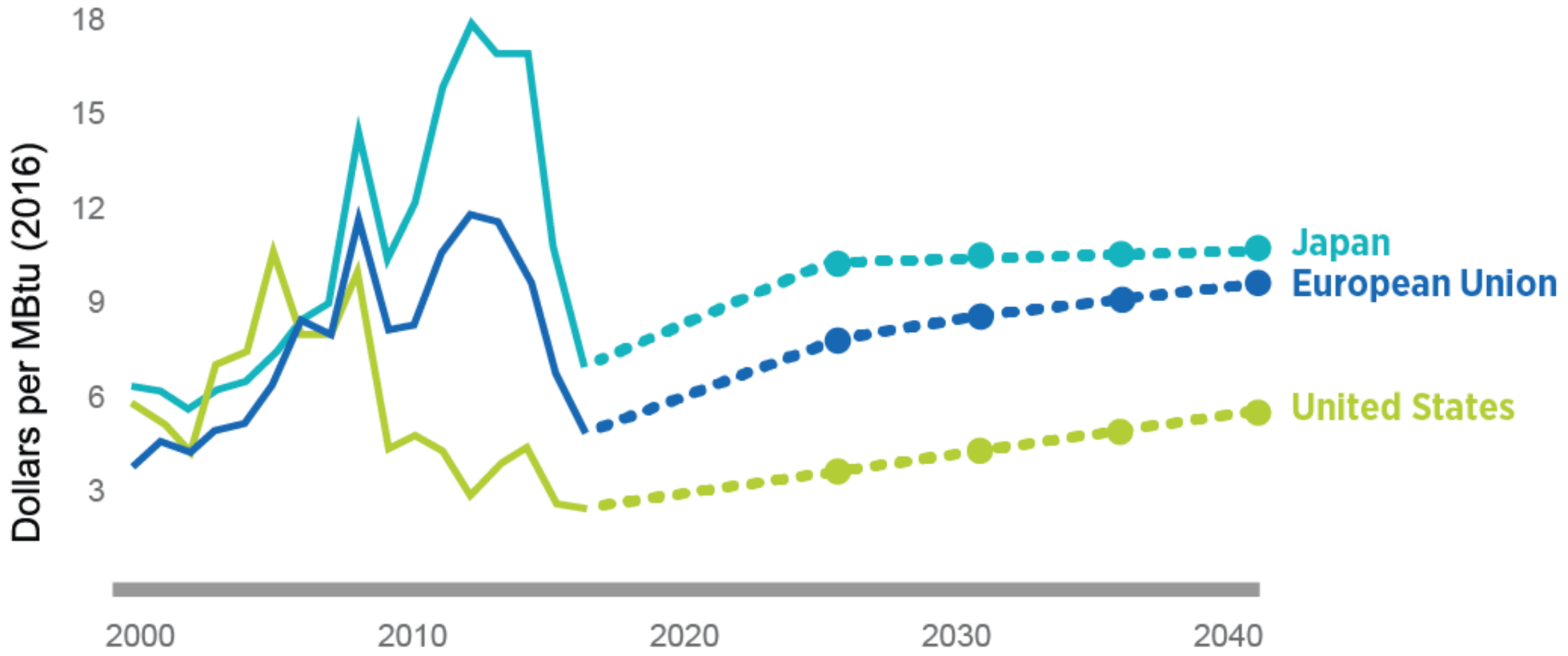

Natural gas prices in the main regions are connected by an increasingly flexible global trade in LNG

Source: IEA 2017 World Energy Outlook

2013 natural gas for trucking was front page news - what happened?

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Differential between natural gas and diesel has largely collapsed in U.S.

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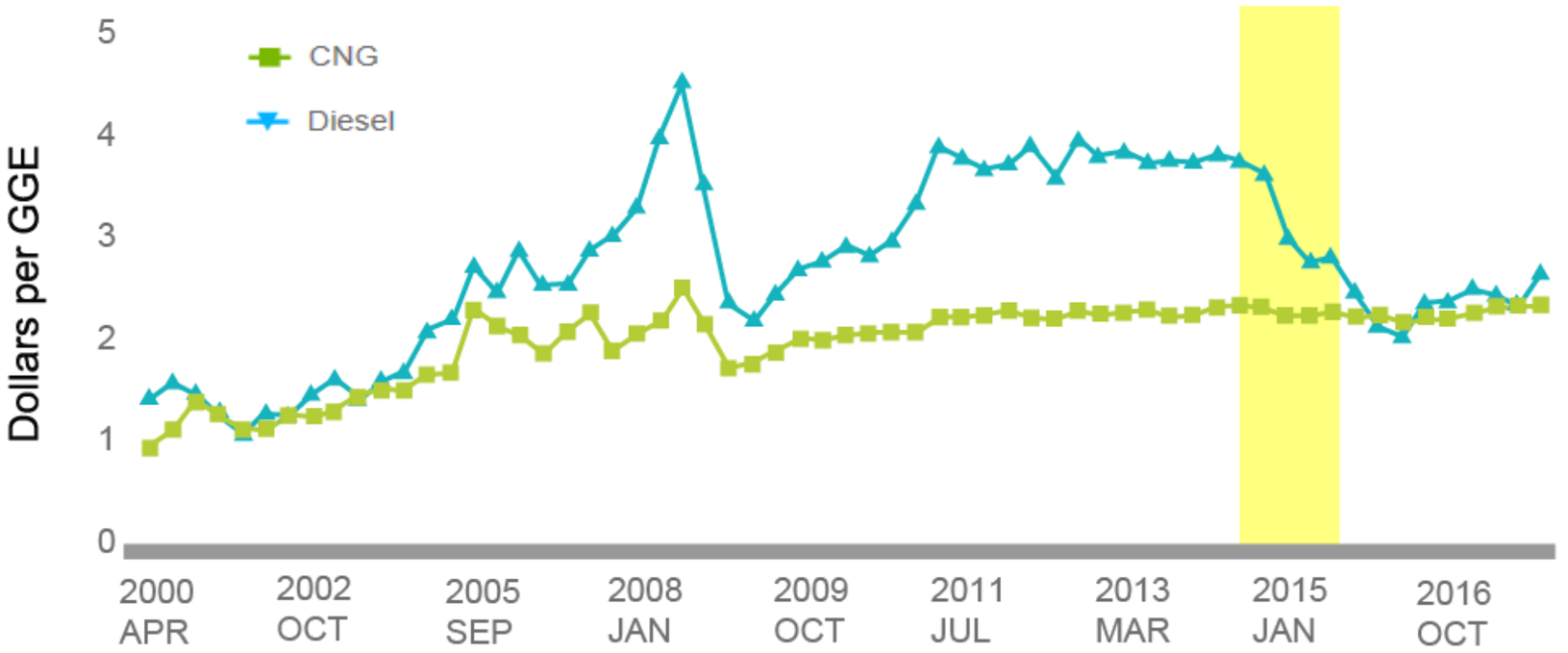
Average retail fuel prices in the U.S.



National average price between October 1 and October 31, 2017	
Fuel	Price
Biodiesel (B20)	$2.68/gallon
Biodiesel (B99-B100)	$3.38/gallon
Electricity	$0.12/kWh
Ethanol (E85)	$2.10/gallon
Natural gas (CNG)	$2.17/GGE
Liquefied natural gas	$2.60/DGE
Propane	$2.78/galon
Gasoline	$2.49/gallon
Diesel	$2.76/gallon

Price differential between diesel and CNG collapsed in late 2015

Source: U.S. Energy Information Administration and Alternative Fuel Price Report, October 2017

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Extensive natural gas pipelines already exist in North America – part of infrastructure is in place

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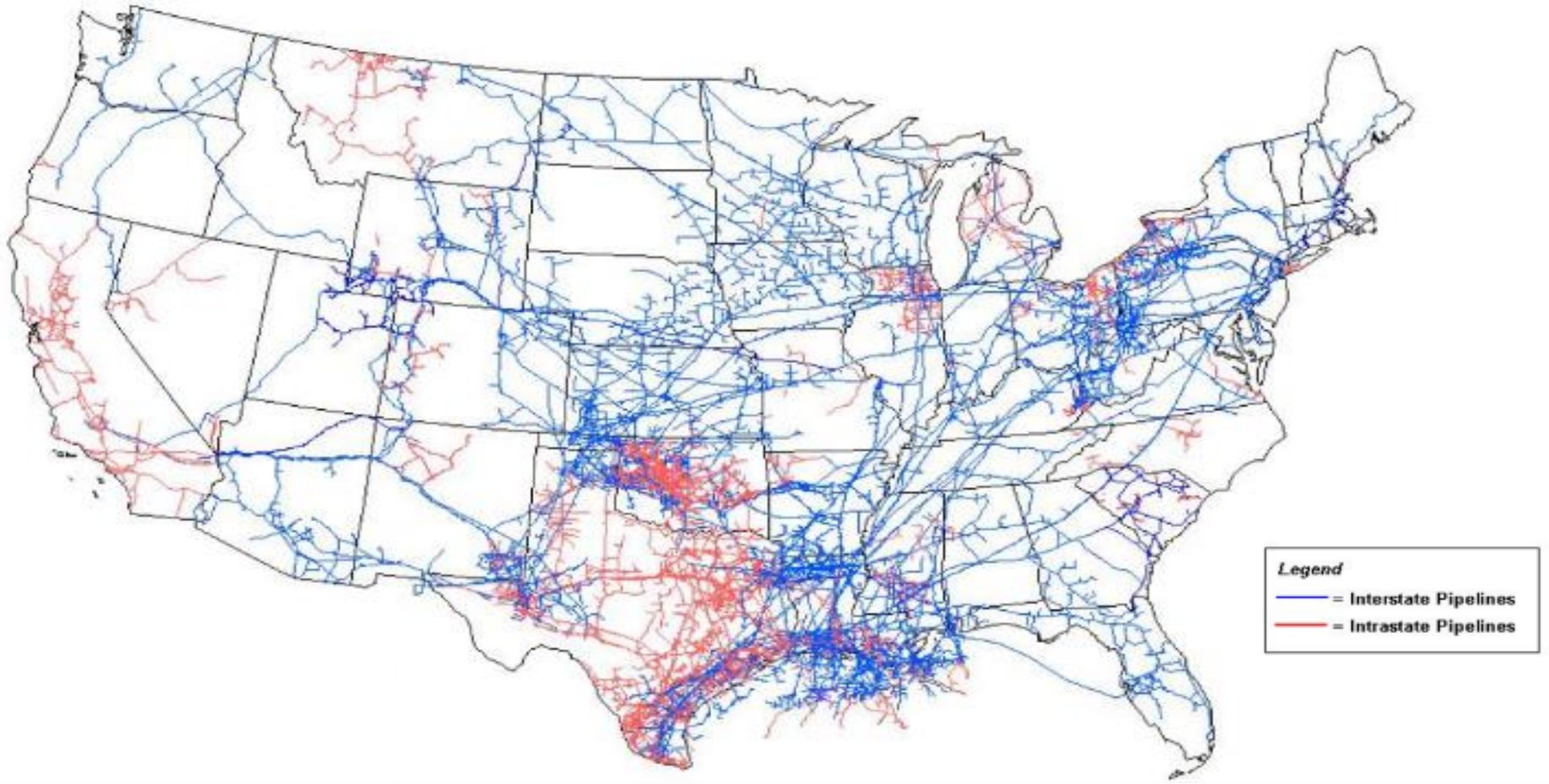
- 305,000 miles of interstate and intrastate natural gas pipelines
- Does not include 2 million miles of local distribution and service lines



There are 1,741 CNG and 143 LNG fueling stations in the U.S

Source: U.S. Energy Information Administration, Office of Oil & Gas, Natural Gas Division, Gas Transportation Information System

U.S. CNG stations concentrated in high population areas

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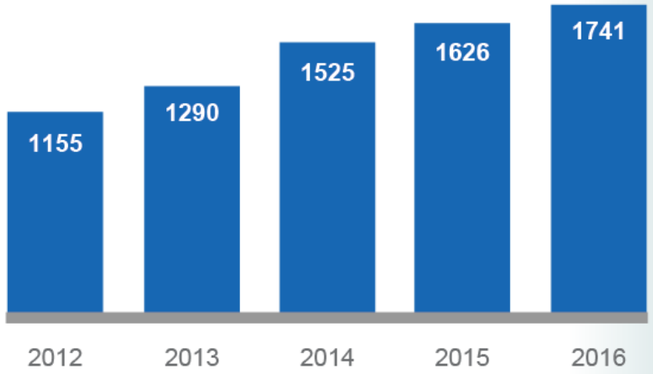
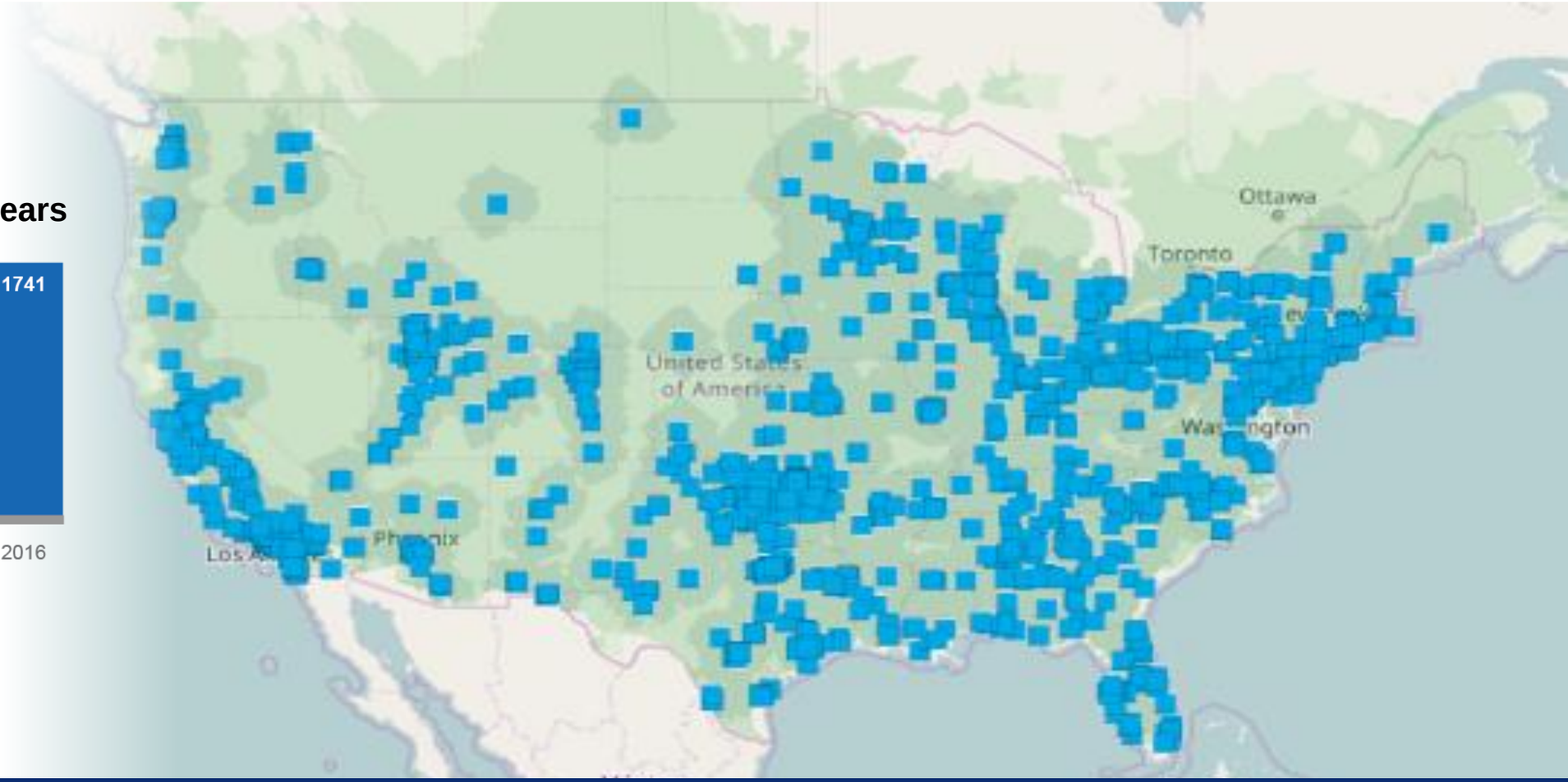
U.S. CNG station growth – 5 years





There is a mix of private and public stations

Source: Natural Gas Vehicles for America

U.S. LNG station network is sparse, but growing LNG corridor being built

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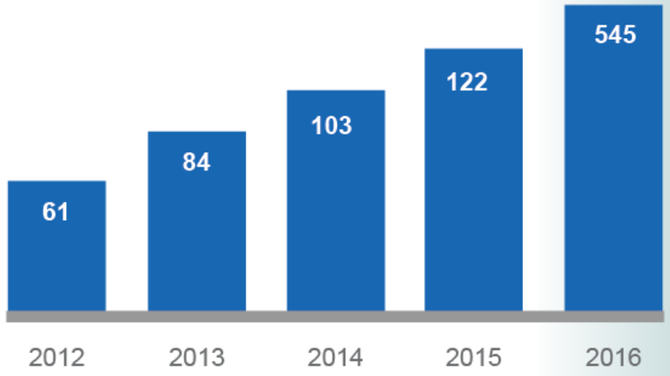
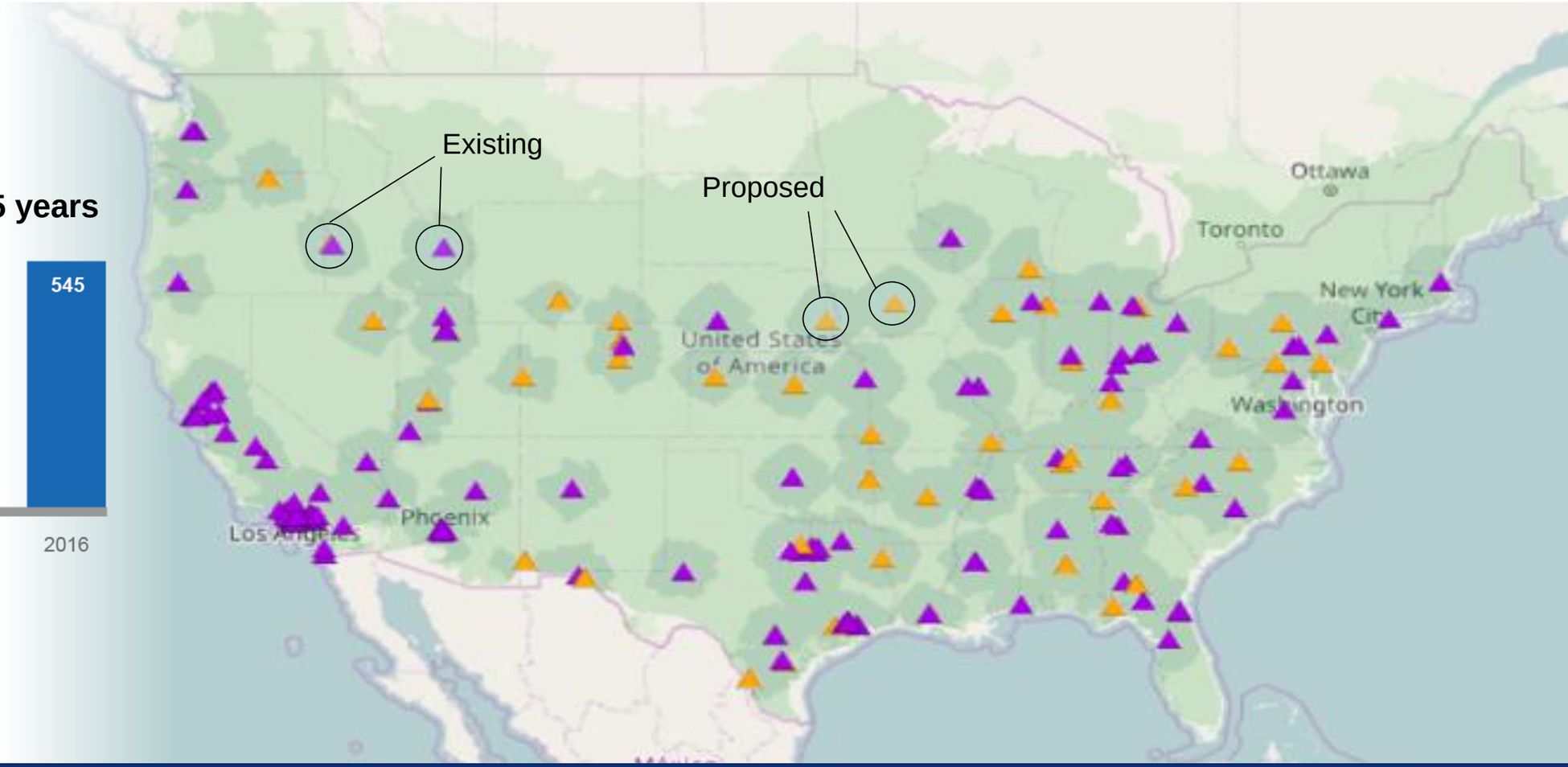
U.S. LNG station growth – 5 years





Primary areas for LNG are Los Angeles/Las Vegas corridor and Texas Triangle (Houston, Dallas, San Antonio)

Source: Natural Gas Vehicles for America

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Low carbon fuel standard (LCFS) requires lower carbon intensity fuels

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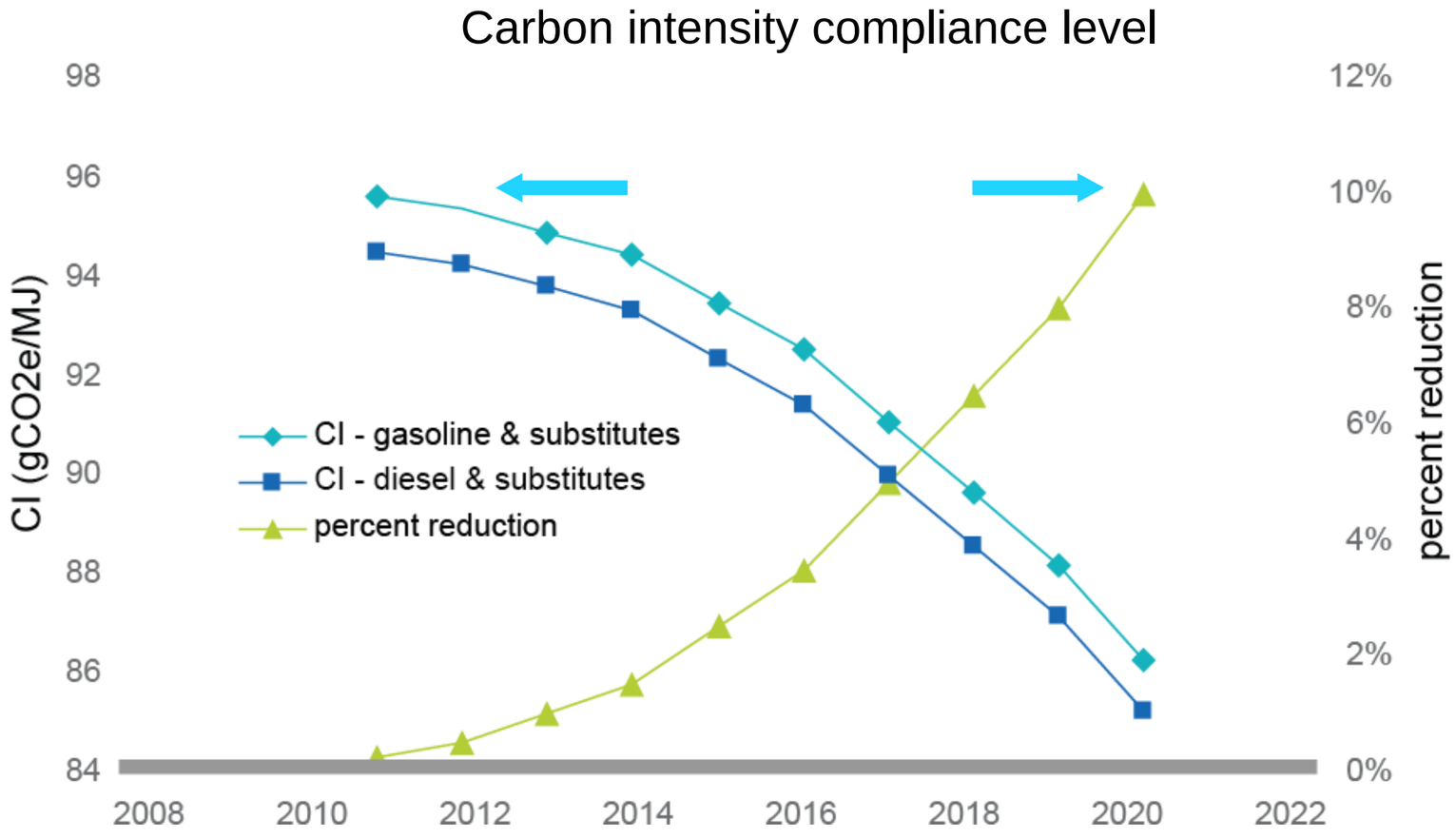

CNG, LNG, and RNG have lower carbon intensities than diesel fuel

Source: California Air Resources Board (CARB)

California low carbon fuel standard (LCFS) encourages supply of natural gas and biogas

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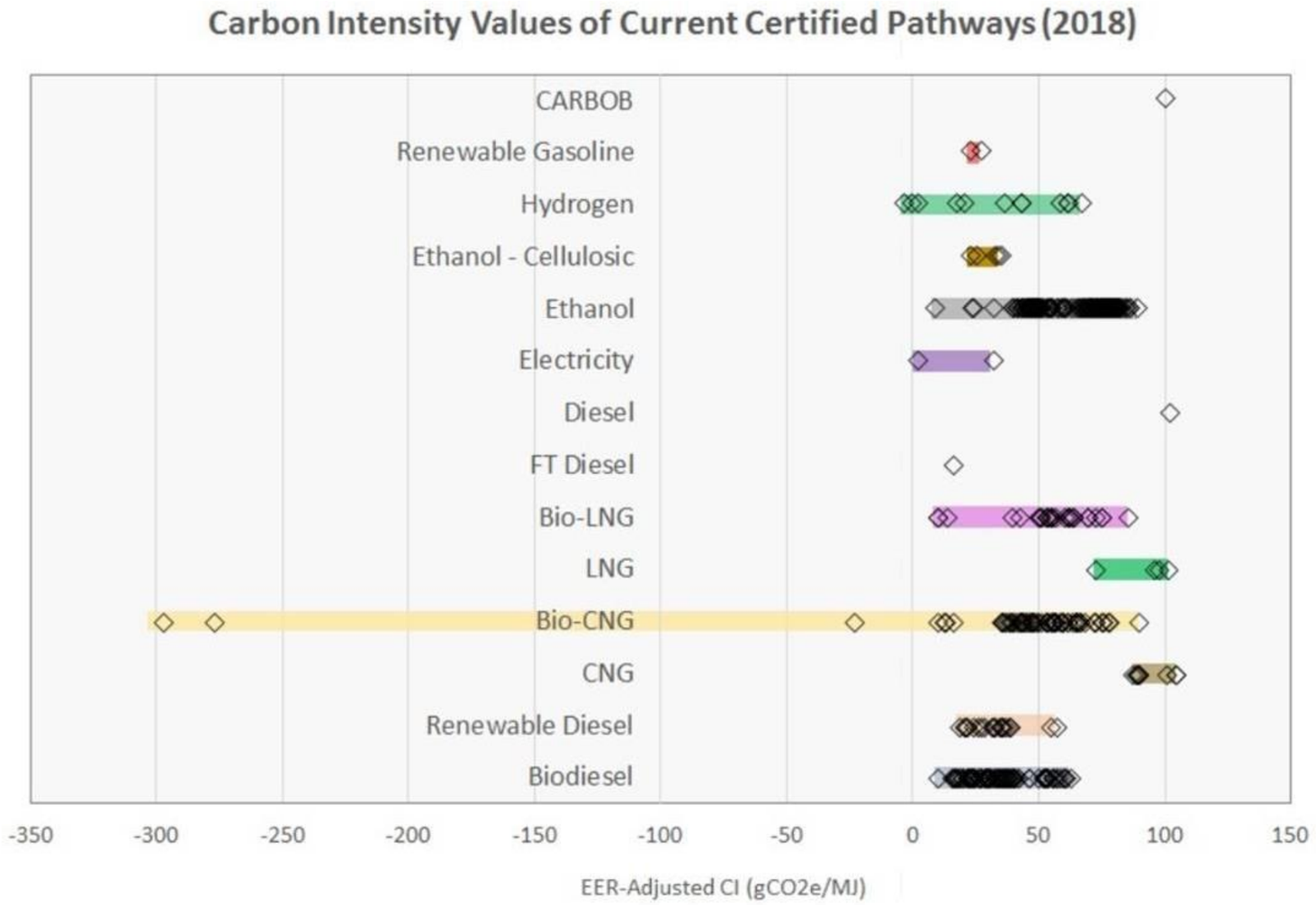

The alternative fuel's CI value is divided by its Energy Economy Ratio (EER) in order to obtain the EER-adjusted CI value, representing the emissions which occur from the use of alternative fuel per MJ of conventional fuel displaced.

Source: California Air Resources Board (CARB)

China/India - Rapid growth of economies has lead to congestion and emissions problems

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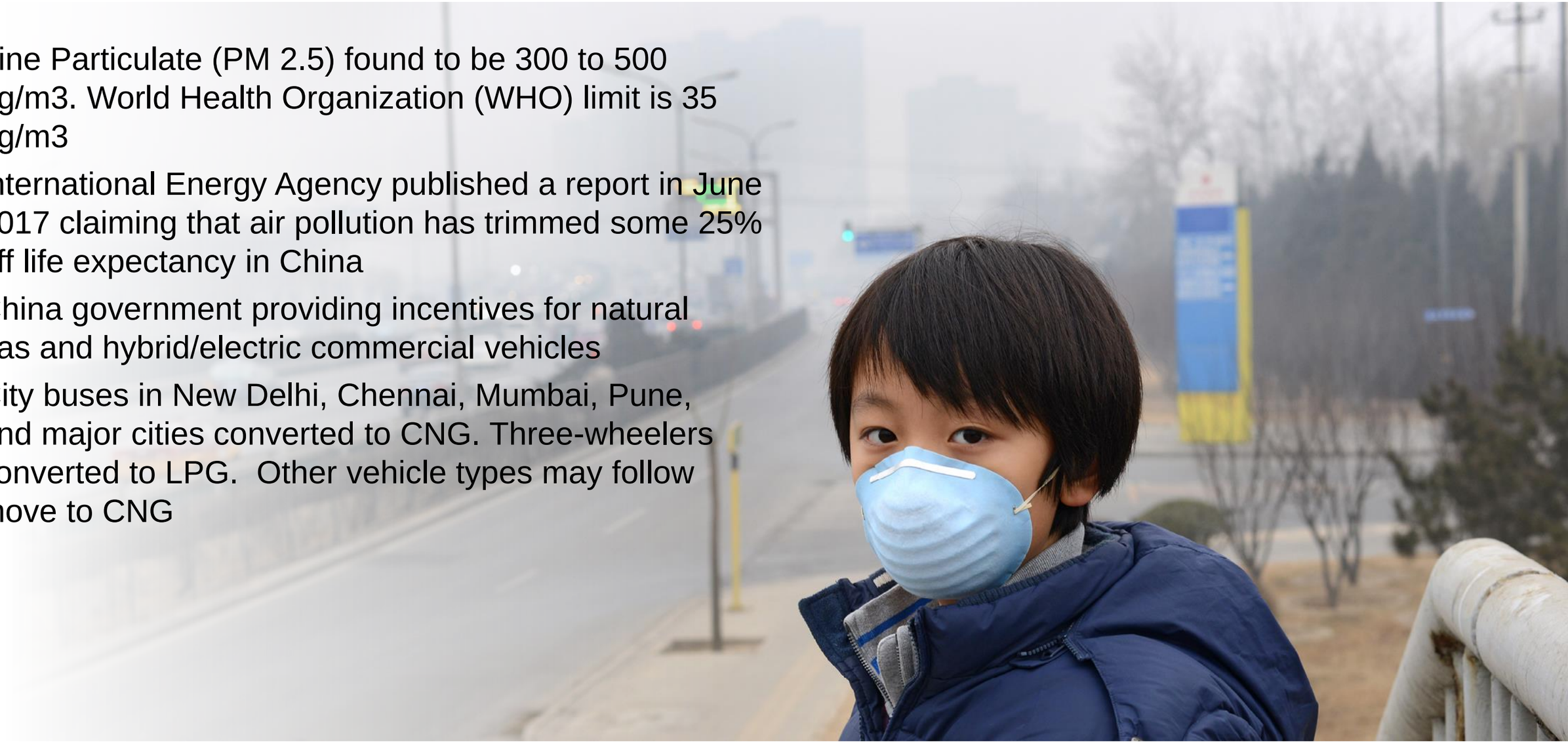
- Fine Particulate (PM 2.5) found to be 300 to 500 µg/m3. World Health Organization (WHO) limit is 35 µg/m3
- International Energy Agency published a report in June 2017 claiming that air pollution has trimmed some 25% off life expectancy in China
- China government providing incentives for natural gas and hybrid/electric commercial vehicles
- City buses in New Delhi, Chennai, Mumbai, Pune, and major cities converted to CNG. Three-wheelers converted to LPG. Other vehicle types may follow move to CNG



Diesel trucks largest source of NOx emissions in some regions

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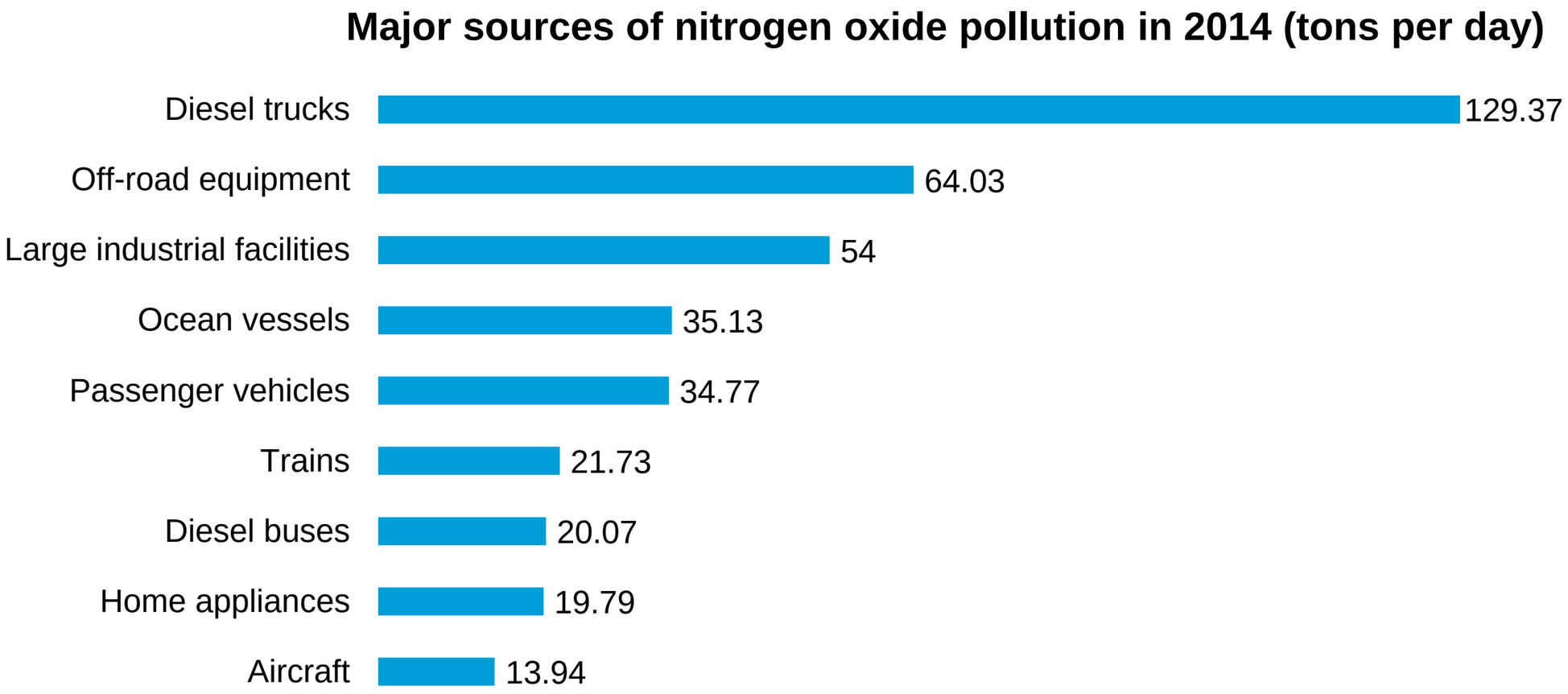

Trucks are largest generator of NOx emissions in critical California South Coast air basin

Source: California South Coast Air Quality Management District

Diesel trucks produce high levels of NOx at low road speeds

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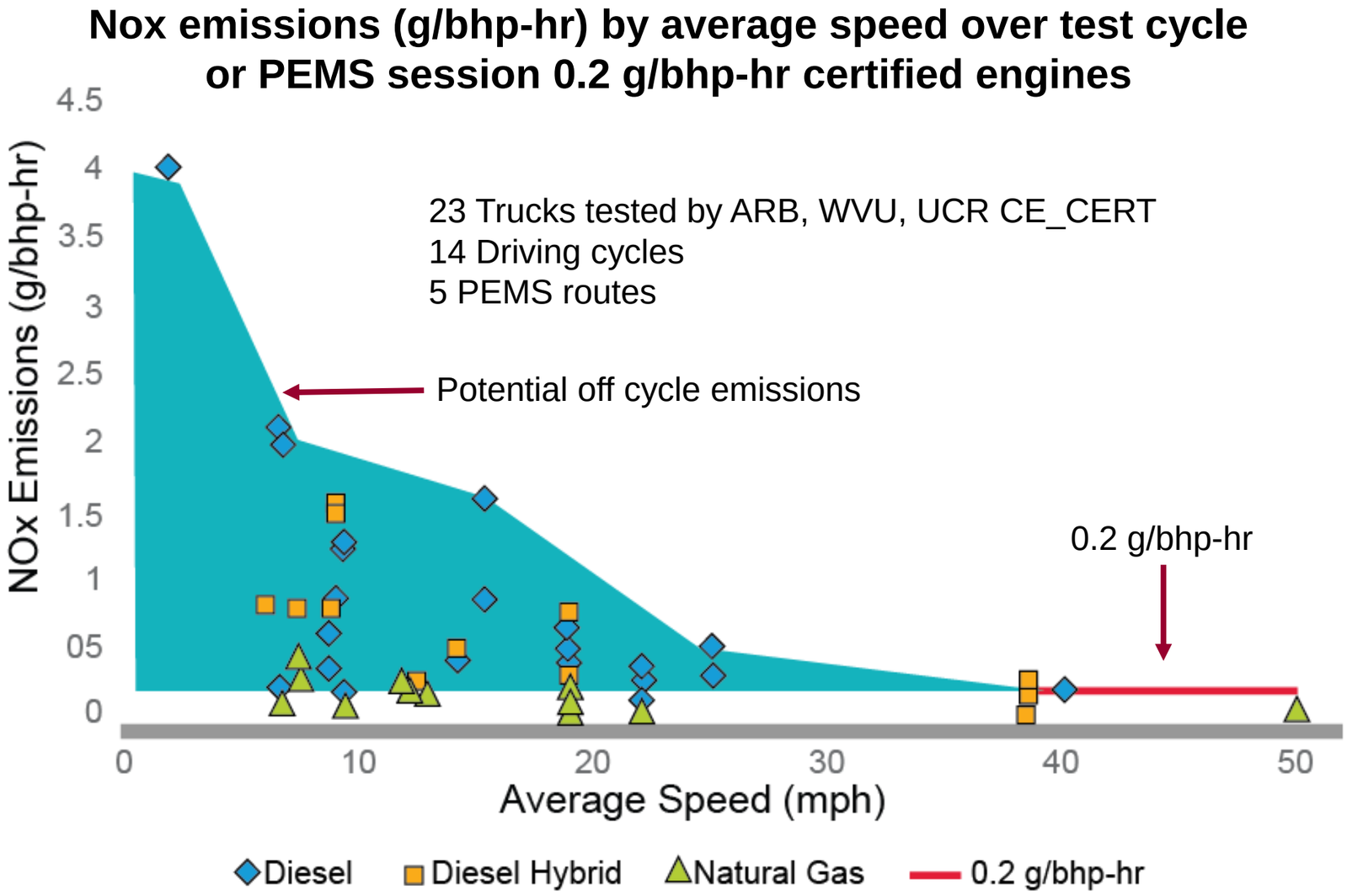

Source: California Air Resources Board

Possible further tightening of NOx standards

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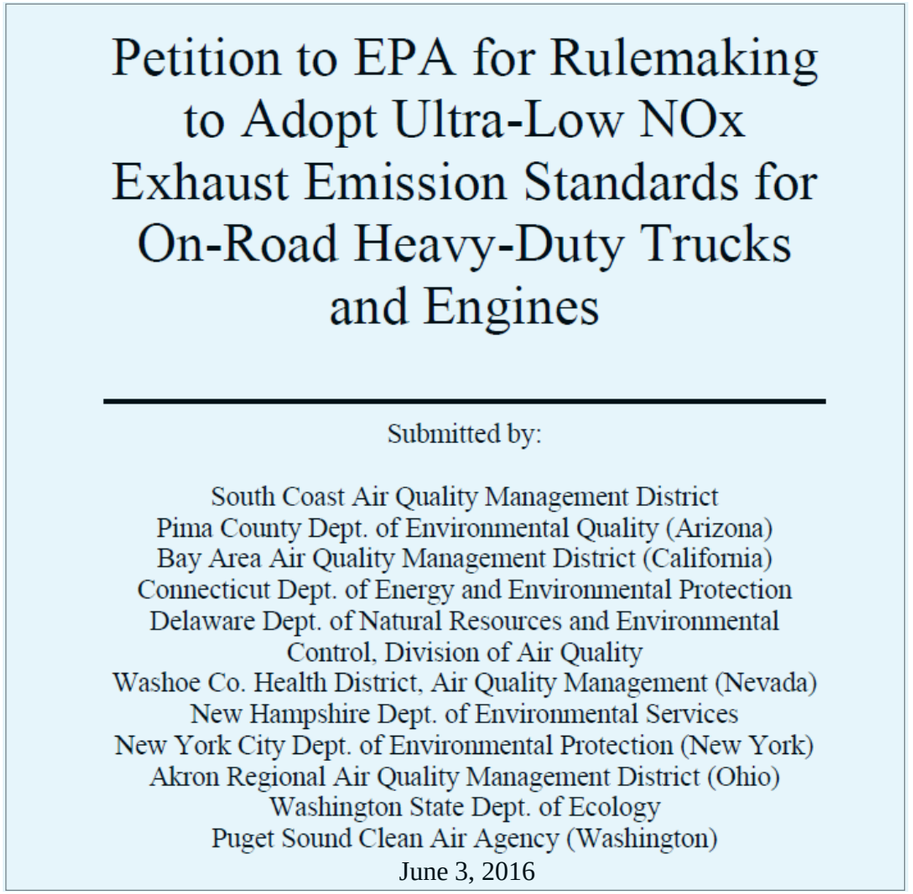
- California Air quality standards for PM and Ozone will be exceeded even with conversion of truck population to 2010 emissions levels by 2023
- NOx creates Ozone
- NOx contributes to secondary formation of PM (nitrates)
- Considering new standard with further 90% reduction in NOx emissions
- Could lead to increased use of EGR, modifications to SCR, or HD natural gas



Petition to EPA for Rulemaking to Adopt Ultra-Low NOx Exhaust Emission Standards for On-Road Heavy-Duty Trucks and Engines

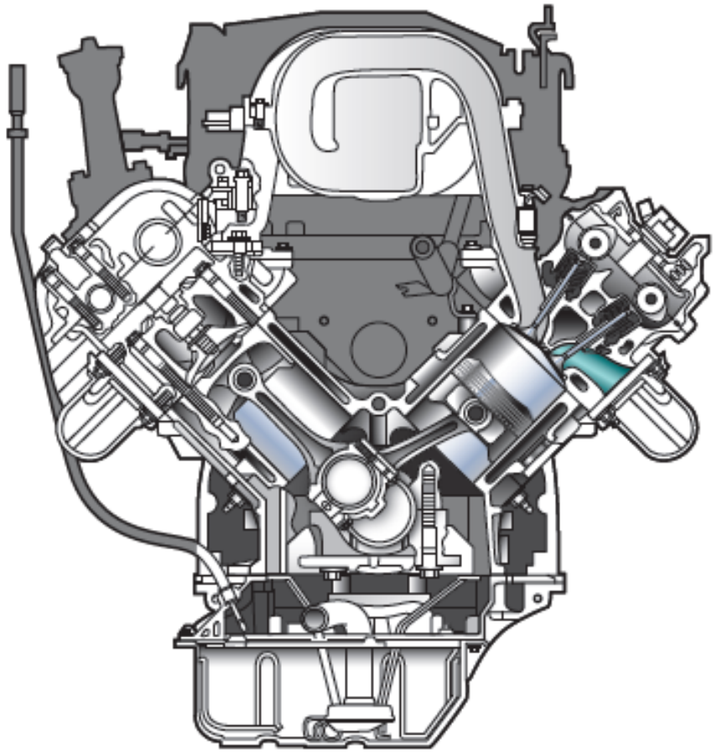
Submitted by:

South Coast Air Quality Management District
Pima County Dept. of Environmental Quality (Arizona)
Bay Area Air Quality Management District (California)
Connecticut Dept. of Energy and Environmental Protection
Delaware Dept. of Natural Resources and Environmental Control, Division of Air Quality
Washoe Co. Health District, Air Quality Management (Nevada)
New Hampshire Dept. of Environmental Services
New York City Dept. of Environmental Protection (New York)
Akron Regional Air Quality Management District (Ohio)
Washington State Dept. of Ecology
Puget Sound Clean Air Agency (Washington)
June 3, 2016

Natural Gas is the only commercially viable alternative for commercial trucks

Cummins Westport “Near Zero” engines

- Cummins Westport have developed and certified three “Near Zero” engines to CARB’s proposed limits:
  - B6.7N
  - L9N
  - ISX 12N
- Diesel solutions are being worked on, but after-treatment will likely be much more expensive than the three-way catalyst used in the Near Zero applications



Field trials taking place with Near Zero engines in Southern California

Major mobile natural gas engines

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Cummins Westport			Weichai	Yuchai	FAW
B6.7N	**L9N**	**ISX 12N**	**WP12NG**	**YC6KN**	**CA6SM2**
• 6.7 liter • SEGR	• 8.9 liter • SEGR • 250-320 hp	• 11.9 liter • 400 hp	• 11.6 liter • China V • TC, electric control fuel injection Lean burn + DOC • Bosch or Woodward fuel systems	• 12.9 liter • China V • OHC, TC, electric control fuel injection Lean burn + DOC • ECI (Econtrols) fuel systems	• 11 liter • China V • OHC, TC, electric control fuel injection Lean burn + DOC • ECI (Econtrols) (note: Woodward and FNG (own) fuel systems can be used for different engines)
• 2016 launch	• Widely used • Over 20,000 in service	• Near-zero emissions • 2018 launch			

Cummins Westport is the dominant supplier in the U.S.

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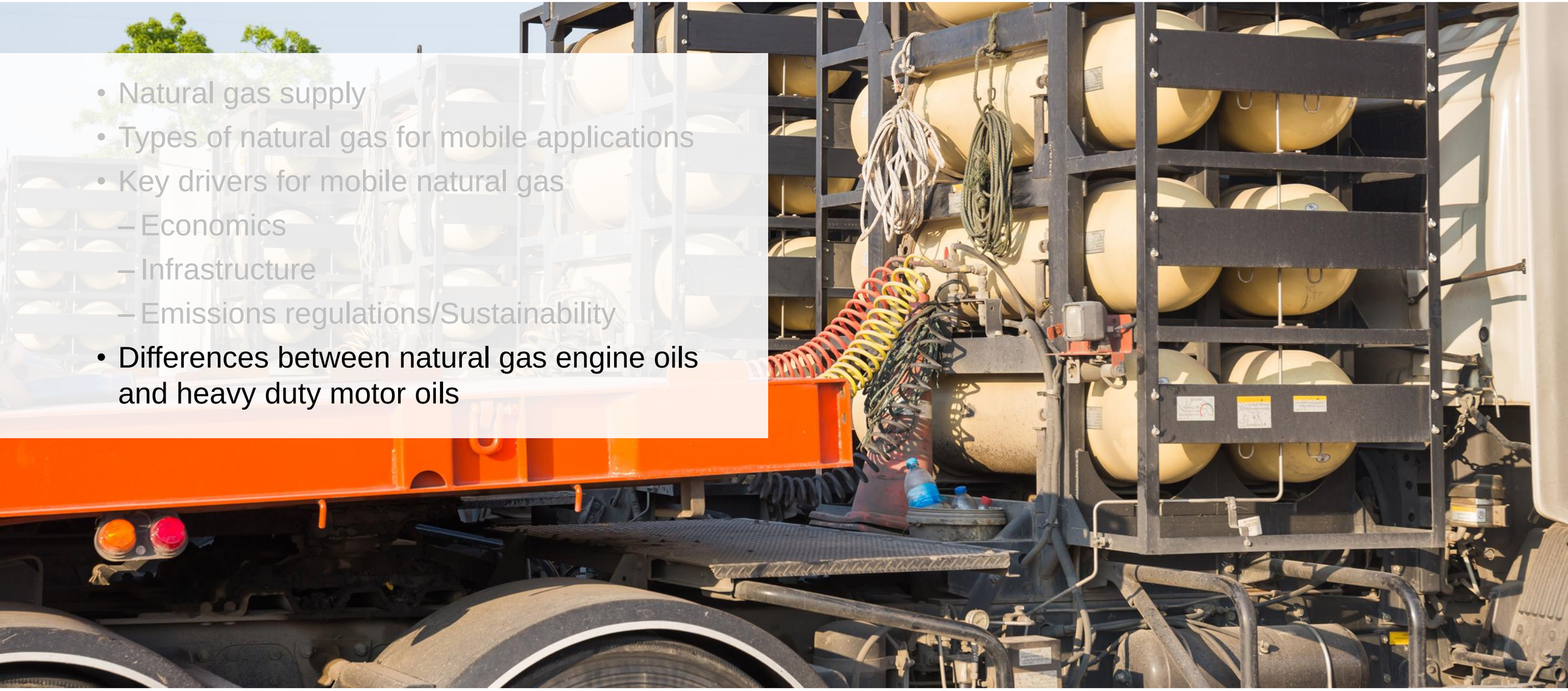

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Requirements for MNGEO are different than HDEO

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Performance Area	HDEO	MNGEO
Soot dispersancy	✓✓✓	
Wear control	✓✓✓	✓✓
Acid neutralization	✓✓✓	✓
Nitration control	✓	✓✓✓
Oxidation control	✓✓✓	✓✓✓
Spark plug fouling		✓✓✓
Valve recession/torching		✓✓
Emulsion performance		✓
Combustion chamber deposits		✓✓
3-Way Catalyst compatibility		✓✓✓
Diesel particulate trap compatibility	✓✓✓	

✓ = relative performance levels

Mobile natural gas and heavy duty diesel engine oils have different performance requirements

Key drivers for new technology development

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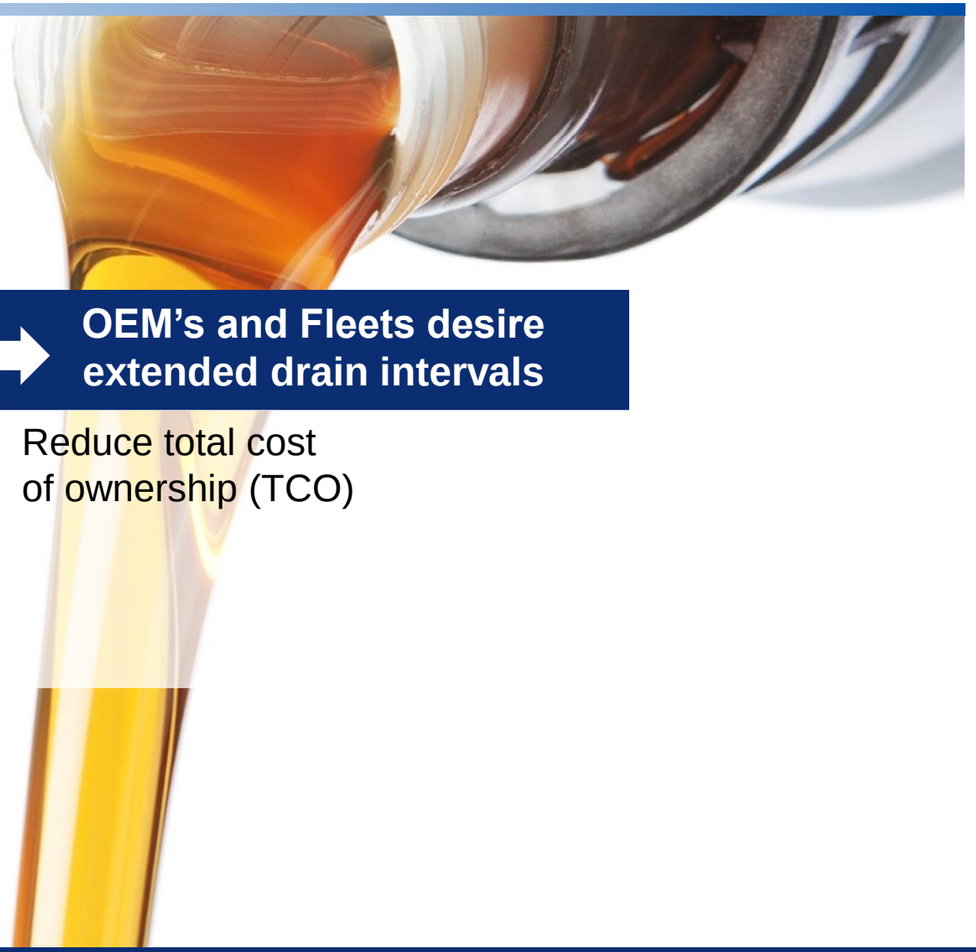

Natural gas engine demand is increasing	Engine technology	OEM's and Fleets desire extended drain intervals
Heavy duty clean running compressed natural gas/liquid natural gas trucks globally	• Ultra low NOx emissions • On-board diagnostics • Spark-ignited stoichiometric combustion with cooled exhaust gas recirculation	Reduce total cost of ownership (TCO)

There is a growing need for high performance mobile natural gas engine oils

Next generation MNGEO is being introduced

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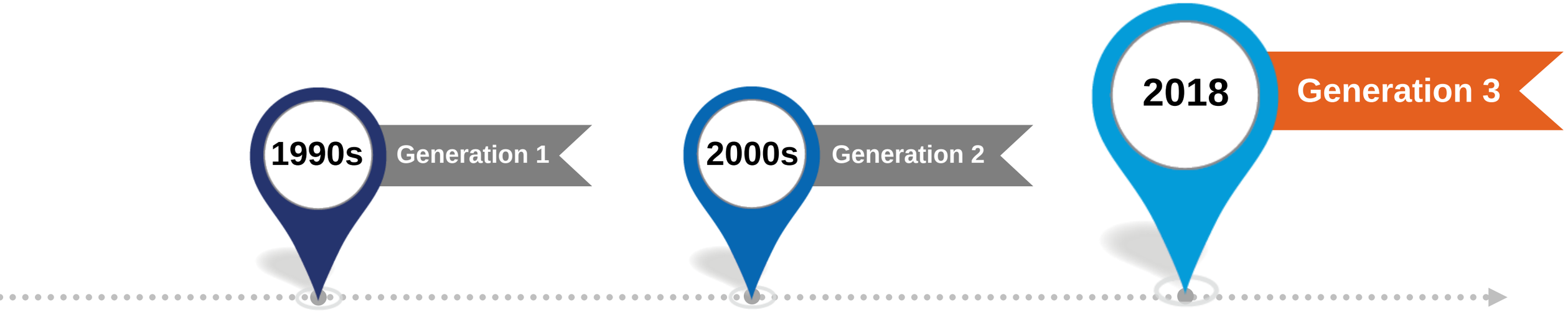

CES 20074

- Ash control
- Special for gas engine

CES 20085

- Extend ODI
- Ash optimized

CES 20092

- For advanced engine
- Enhanced oxidation & nitration
- LSPI
- Extend ODI

Comparison of oxidation performance generation 2 and generation 3 MNGEO

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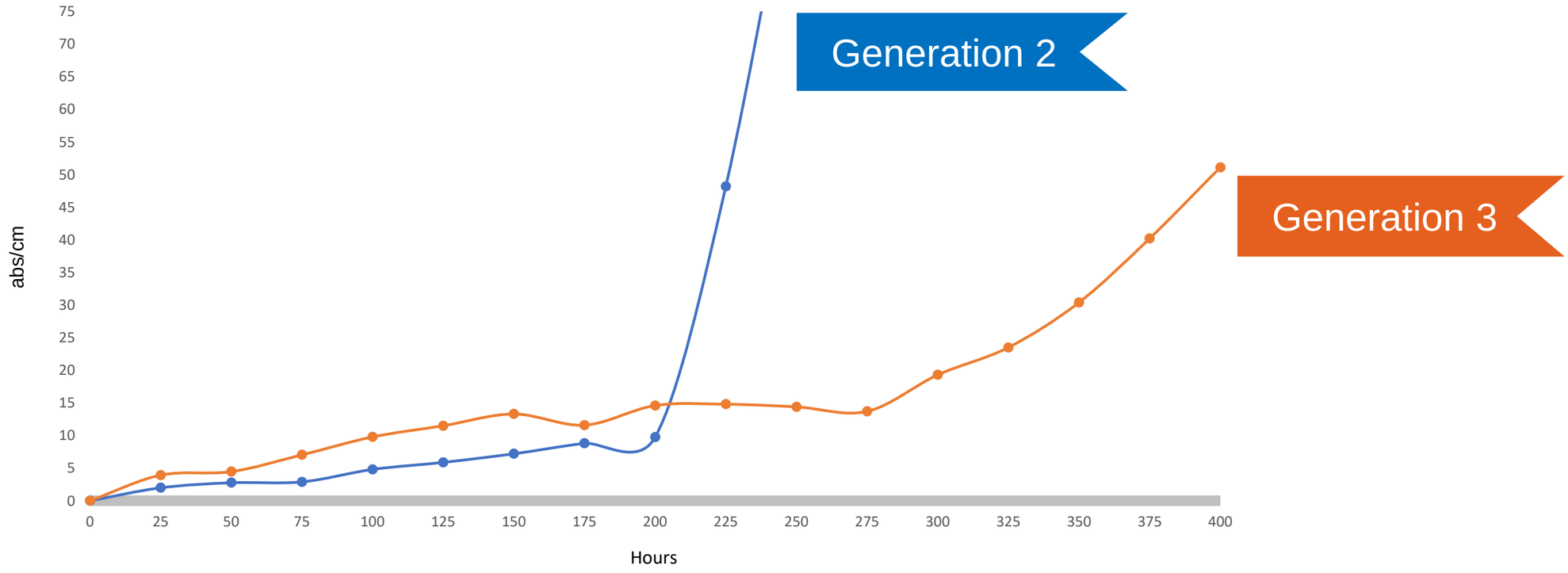
FTIR Oxidation peak height



Generation 3 provides extended drain capability

Summary

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- Natural gas availability, economics, and price stability have improved significantly with new production technologies (e.g. fracking)
- Emissions regulations and favorable economics are driving new investments in mobile natural gas, particularly in U.S., China and India – better infrastructure needed
- Natural gas combustion is inherently cleaner than diesel and tailpipe gaseous emissions can be minimized through three-way catalyst technology. Particulate matter emissions are minimal
- Renewable Natural Gas (RNG) can be used where available
- For optimal performance, Natural Gas Engines require MNGEO