Near Zero Emissions

Engine Technologies For Heavy Duty Transportation

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Engine Webinar
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Southern California Gas Company

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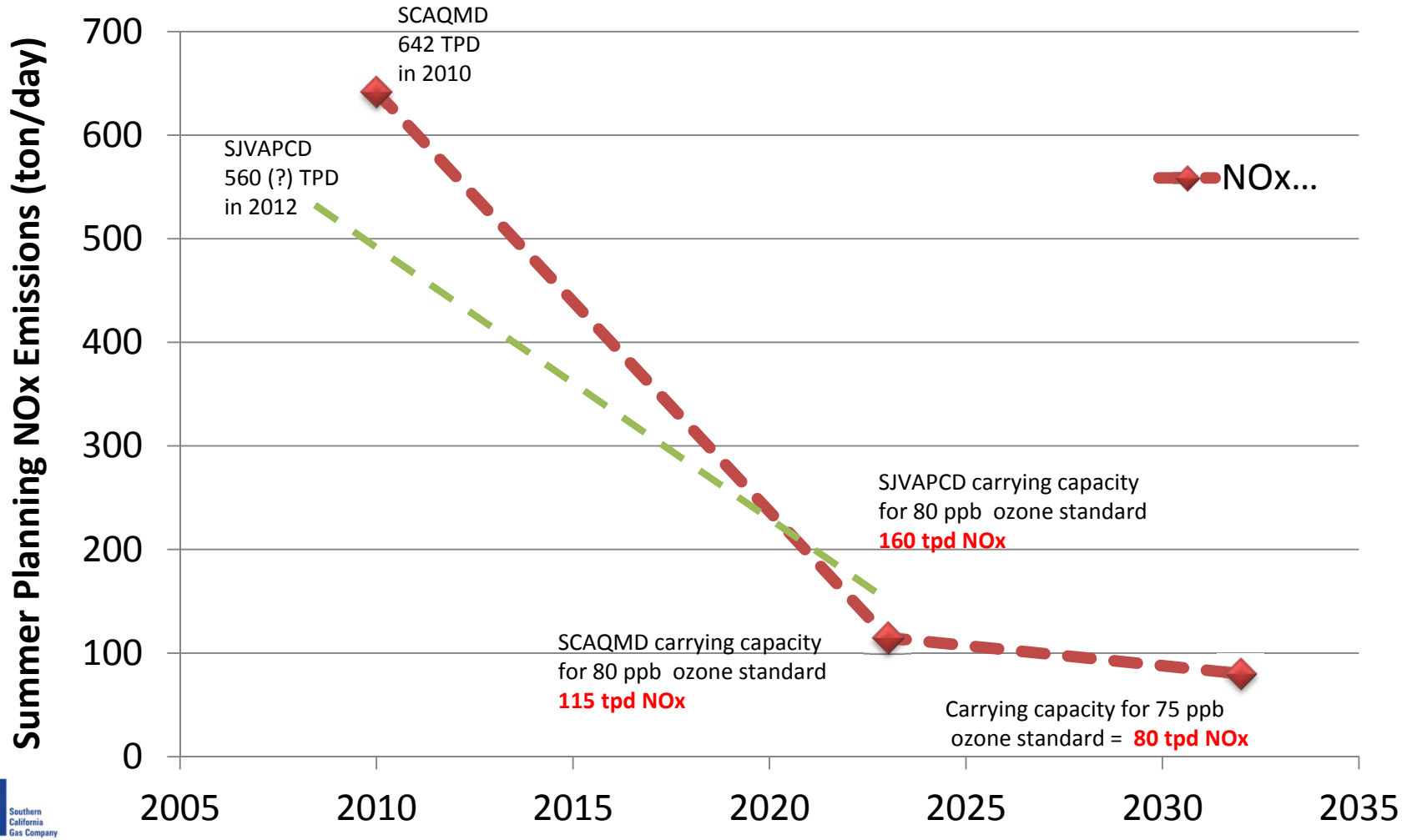
LA Basin and San Joaquin Valley Need More Emission Reductions, Sooner



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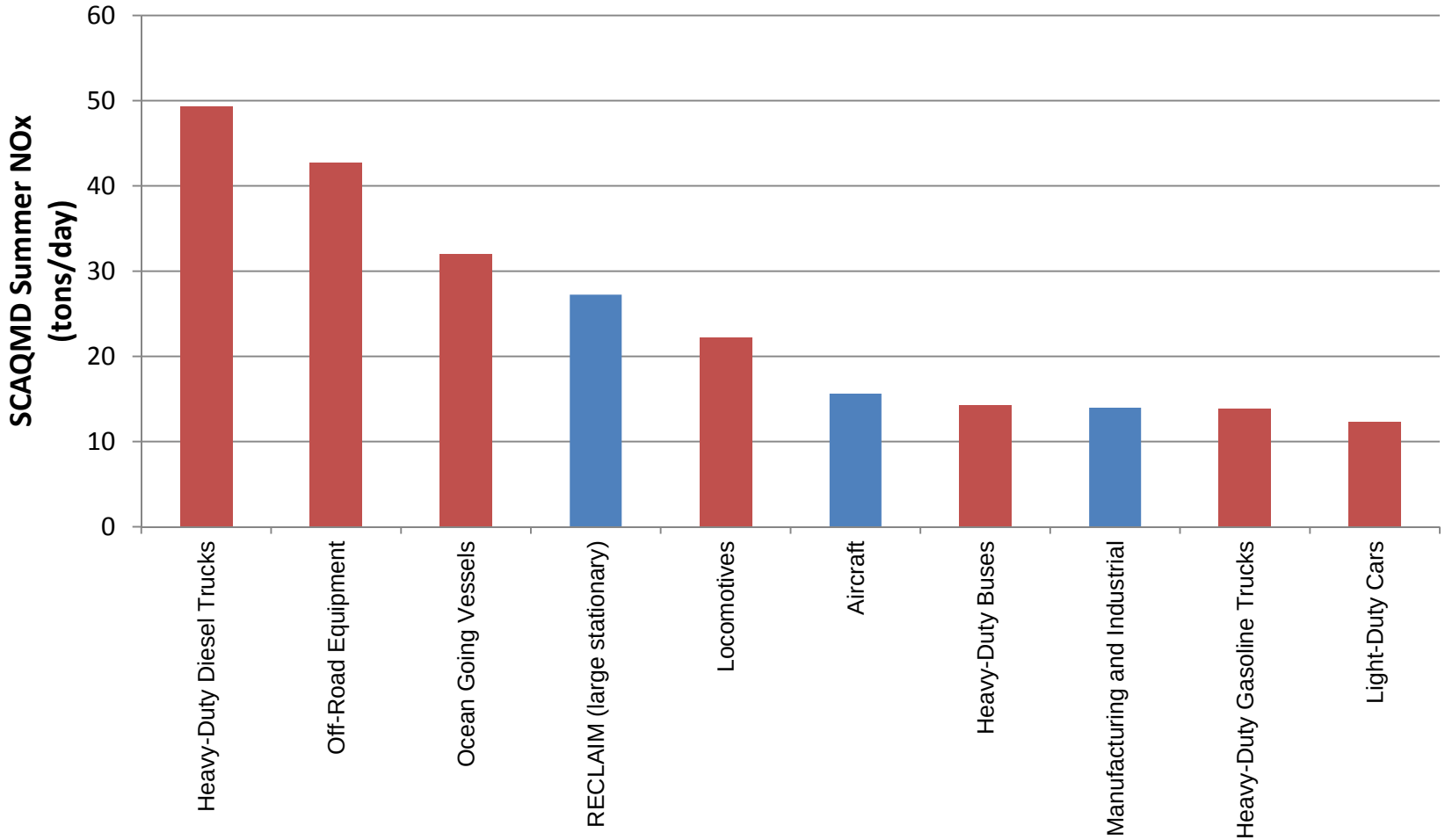
Mobile Sources with Good Potential for Conversion to NG

(in red)

(298 tons/day out of total 319 tons/day)

Top 10 NOx Source Categories (*2023 projections*)



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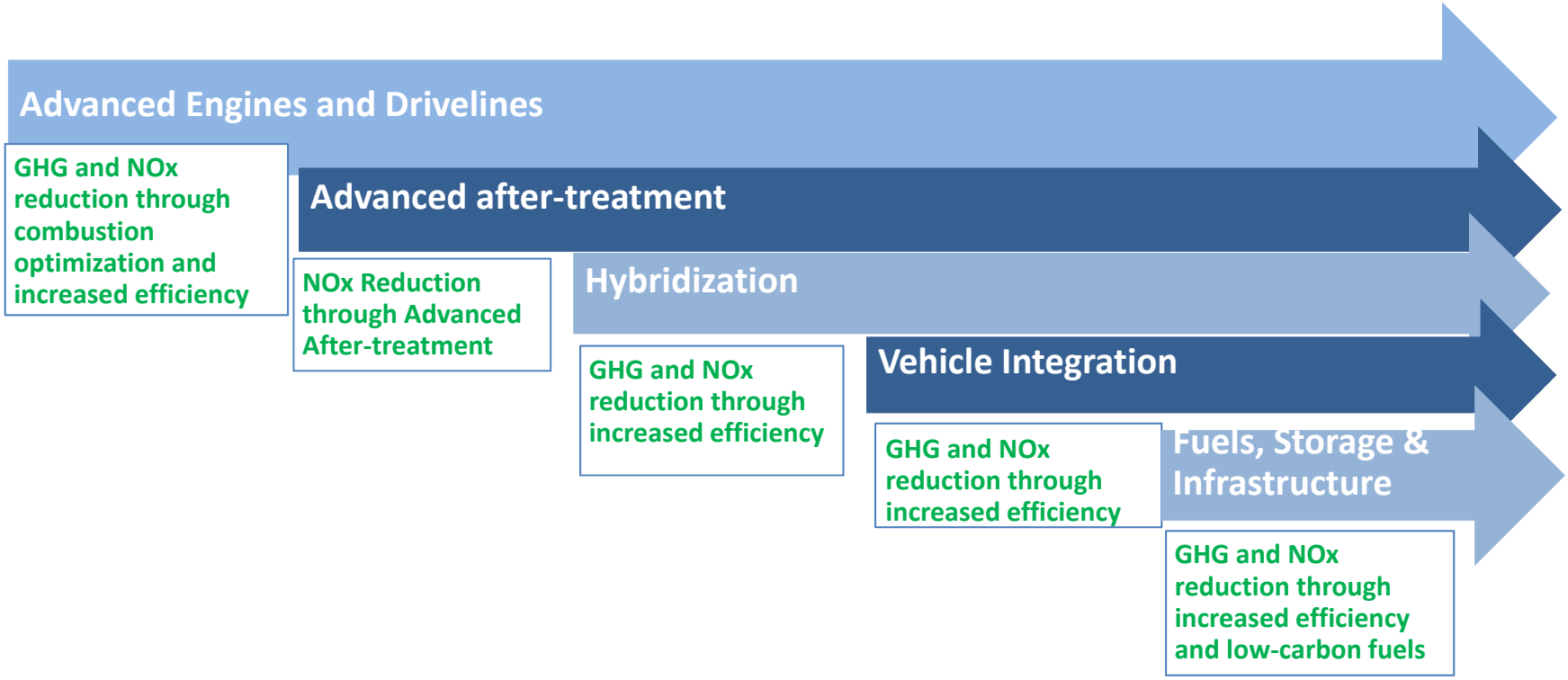
Five Strategies for Emission Reductions

Goals

NOx: Reduce to ZE-equivalent ~ 90% below EPA 2010/Tier 4

GHGs: Reduce to 2050 goals ~ 80% below current levels



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Technology Advancements to Reduce Emissions and Increase Engine Efficiency

Goals

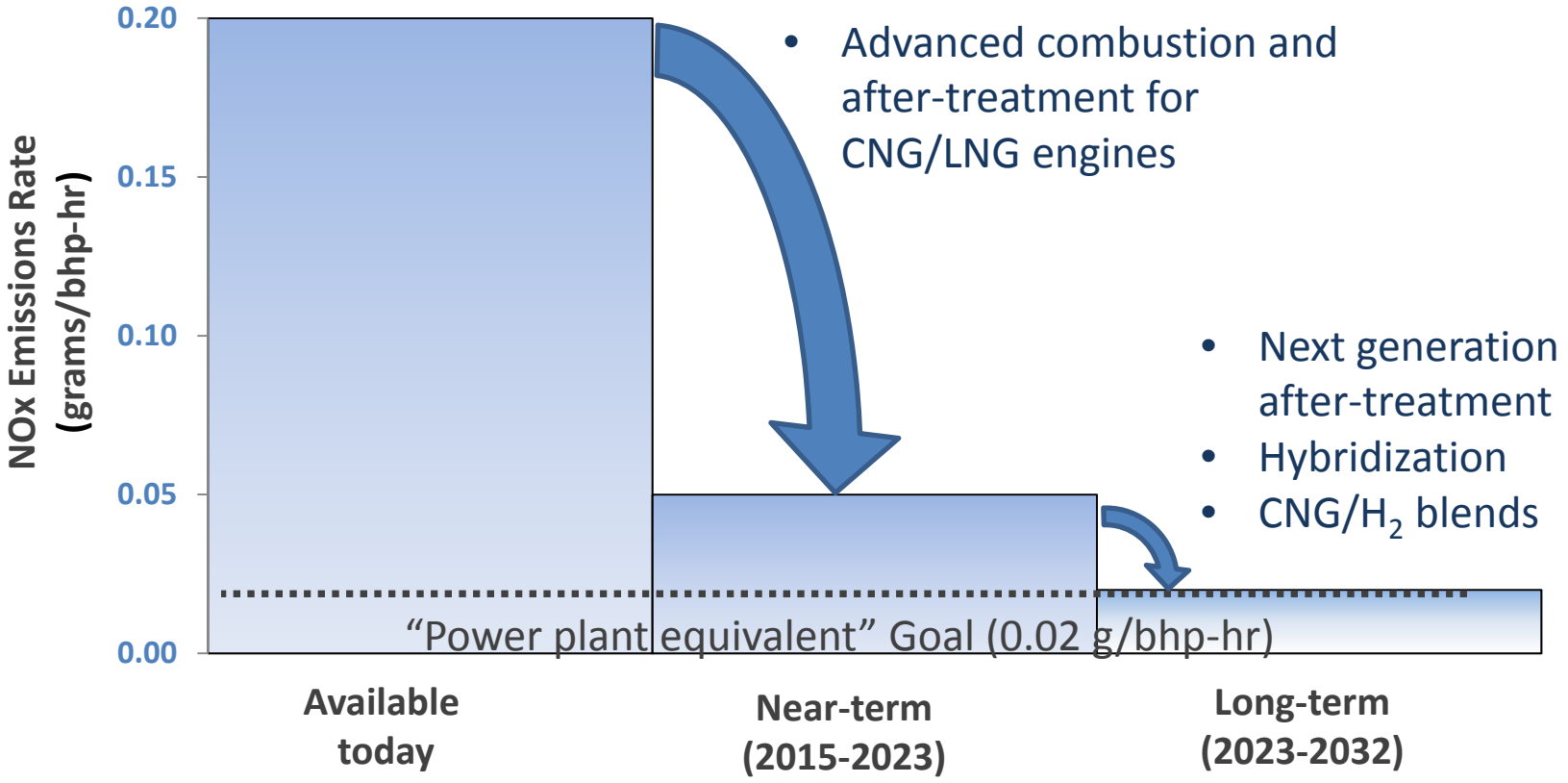
NOx: Reduce from 0.2 Gr/Bhp-Hr to 0.02 Gr/Bhp-Hr

Increase Thermal Engine Efficiency From ~35 to 50%

Technology Advancements

Advanced Engines	Advanced After-Treatment	Hybridization	Vehicle Integration	Fuels, Storage & Infrastructure
•New or enhanced combustion strategies •Optimized Compression Ratios •On Board Diagnostics •Advanced Sensors/Controls •Innovative and Advanced Cycles Atkinson/Miller •Waste Heat Recovery •Camless Engine & HCCI •Multi Port Injection	•Enhanced 3-way Catalyst •Lean burn + SCR •Rich burn + NSCR + EGR •Lean burn + SCR + Oxidation Catalyst •Lean burn + Lean NOx Trap (LNT) •Advanced control +Low speed Pre-ignition	•Various drive-train configurations to capture waste energy to "assist" the primary drive •Hydraulic hybrid •Battery-Electric •Advanced Plug-in range extender (FC, turbines) •Dual Mode Catenary hybrid •Fuel Cell hybrid	•Incremental improvements to known strategies •Aerodynamics •Weight reduction •Tire rolling resistance reduction •Friction & Parasitic reduction	•RNG from organic waste, dedicated crops or sunlight •CNG - Hydrogen blending •Improved compression technology •Low pressure storage

Multiple Strategies to Address NOx Emission Reductions



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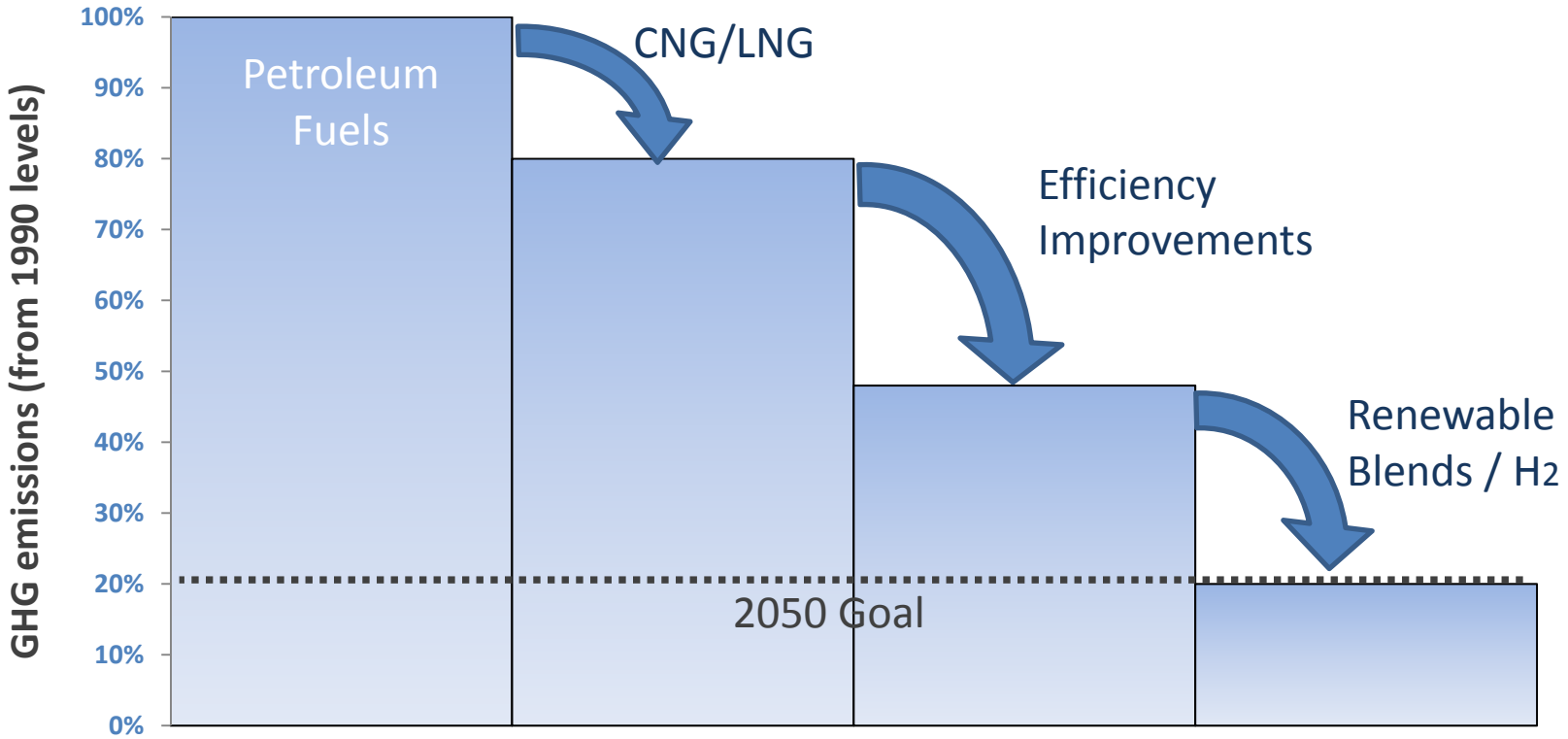
Similar Technology Strategies Can Reduce GHG Emissions

Efficiency Improvements and Renewables Availability Increase Over Time



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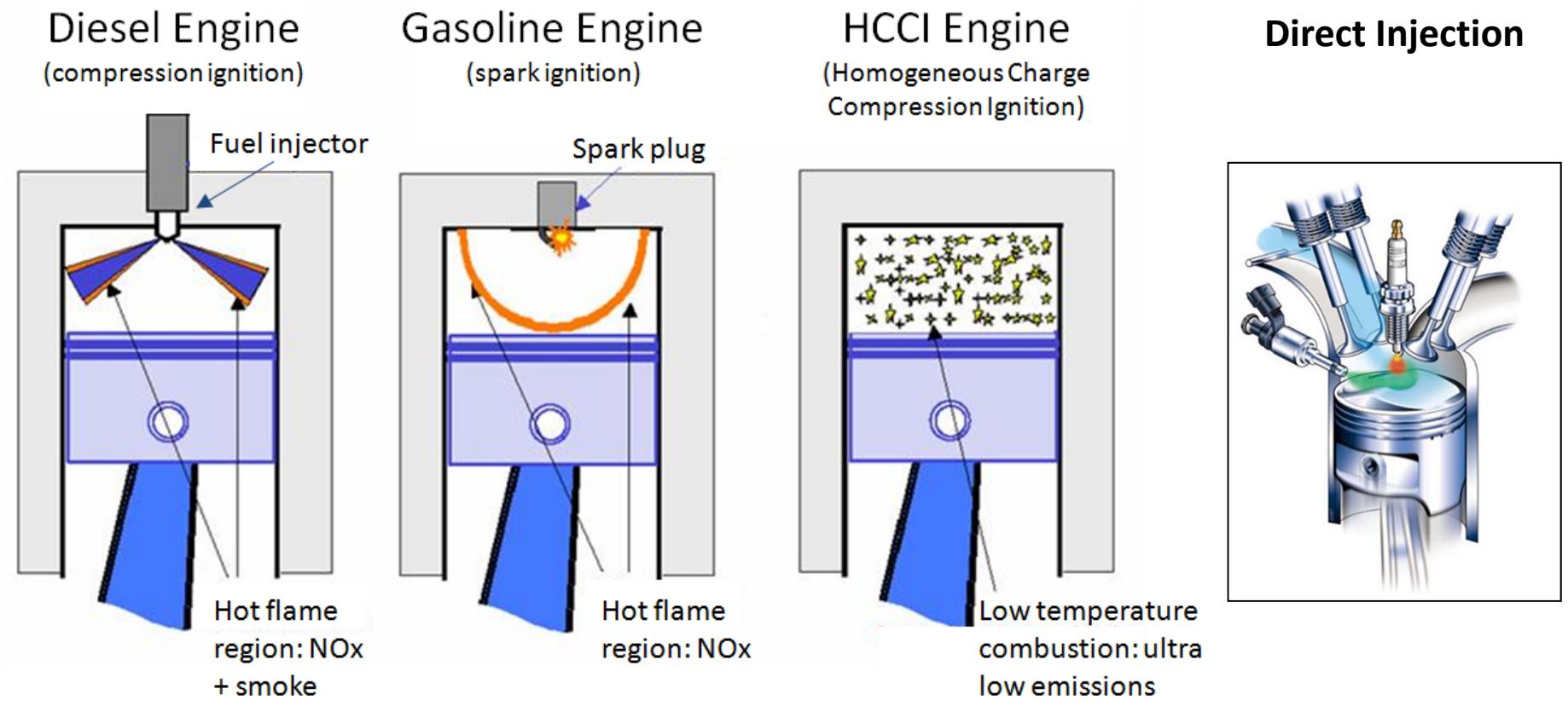
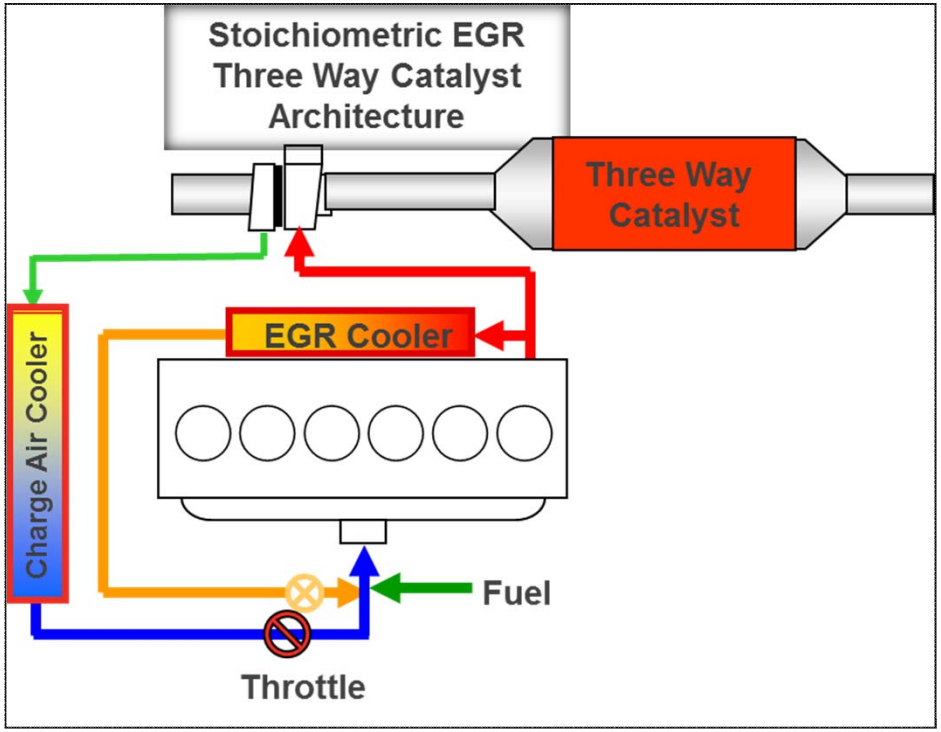
Engine Technology Advancements

- Advanced Combustion – IC Engine
  - Spark Ignition
  - Compression Ignition
  - Homogeneous Charge Compression Ignition (HCCI)
  - Direct Injection (DI)
  - Low Peak Temperature Combustion (LPTC)
  - Camless Engine (Electronic Valve Timing)
  - Sensors & Controls
- Advanced Turbines

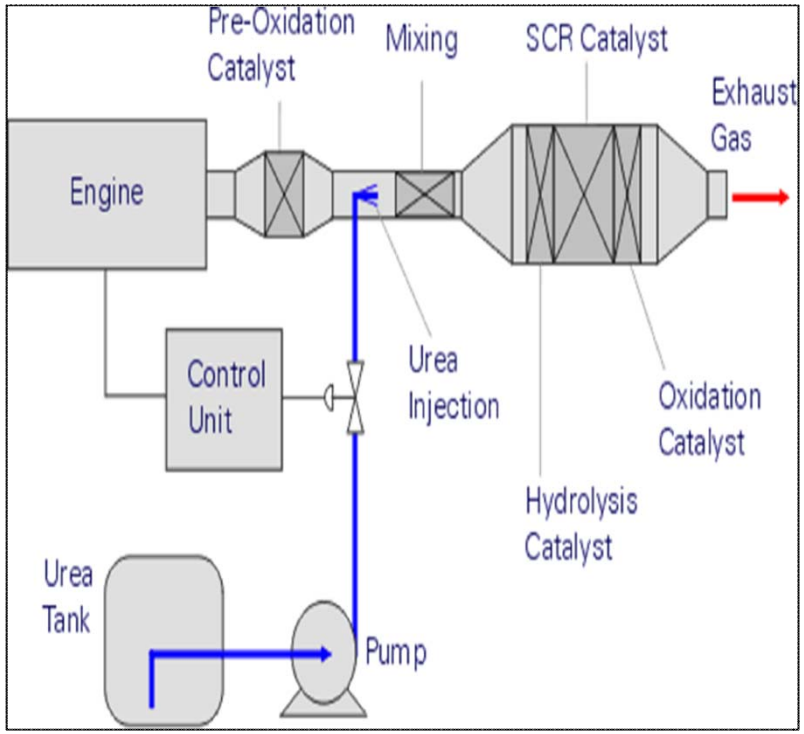
Various Types of Engine Ignitions



Engine Controls and Exhaust Treatment



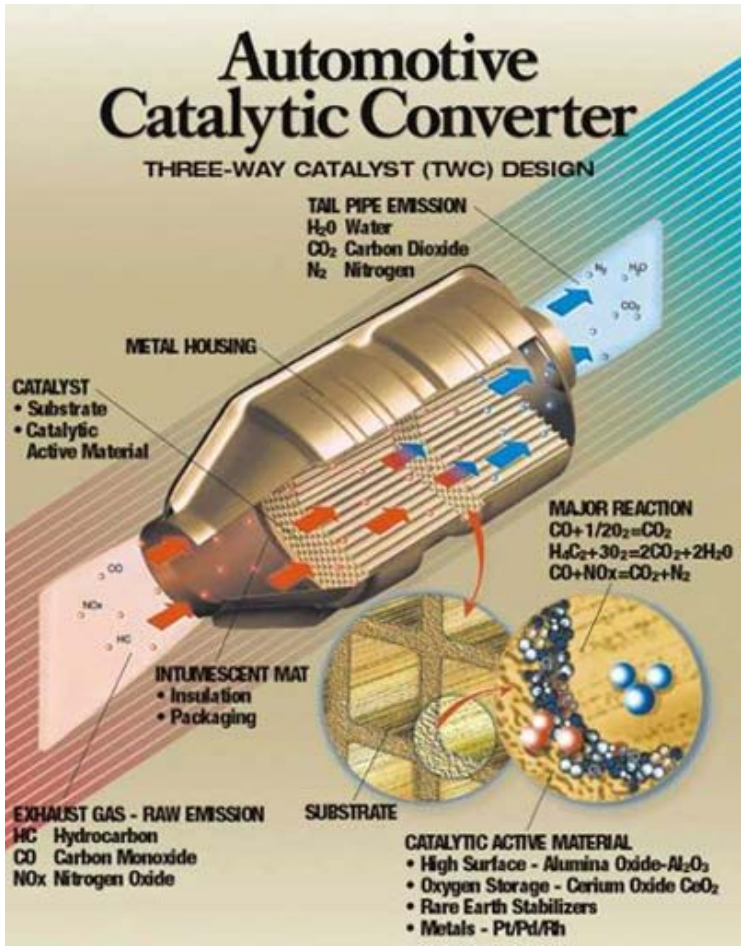
Stoichiometric Engine + NSCR (TWC) + EGR



Lean Burn + SCR + Ammonia/Urea

Other Technology Advancements

- Advanced After Treatment
  - Selective Catalytic Reduction (SCR)
  - Non-Selective Catalytic Reduction (NSCR)
  - Lean NOx Catalyst (LNC)
- Waste Heat Recovery
  - Bottoming Cycle
- Hybridization
- Renewable Natural Gas



Next Generation Refuse/Transit

Project Overview

- Develop dedicated natural gas engine with near zero emissions without sacrificing performance or efficiency compared to 2010 engine standards
- Doosan and SWRI are the technical leads
- On-road testing to begin late 2014 – plan to test 3 vehicles

Potential Benefits:

- 75%+ reduction in NOx emissions
- Similar efficiency and cost to diesel alternatives

Goals & Targets

- Modify 11L 340hp Doosan engine (conversion from lean burn w/SCR)
- Stoichiometric operation, TWC, Cool EGR
- Advanced ignition system for highly dilute mixtures
- Optimized in-cylinder turbulence & High efficiency turbo matching
- Advanced control for knock and misfire detection

Partners

- CEC, DOE, SCAQMD and SWRI

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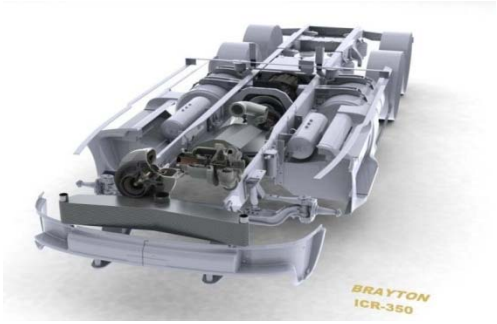
Low Emission Turbine Drive

Project Overview

- Demonstrate near-zero emissions dual liquid/natural gas combustor for existing 350 kW gas turbine engine designed for Class-8 trucks
- Brayton Energy, Kenworth & FedEX -- develop a Class 8 MT dual fuel truck

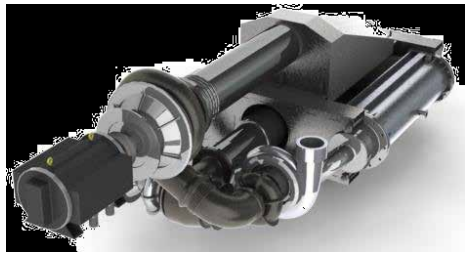
Potential Benefits

- Near-zero emissions (75% NOx improvement) NOx < 0.05 g/bhp/hr, CO< 0.02 g/bhp/hr
- Fuel flexibility
- Improved efficiency from advanced turbine design



Goals & Targets

- Testing of turbine in truck chassis is schedule for late 2013
- First chassis dynamometer runs expected in July 2013
- FedEX will receive the CNG-only truck (made by Kenworth) in late 2013 and operate in 2014 in CA



- ***Partners***
  - CEC, DOE and Brayton Energy

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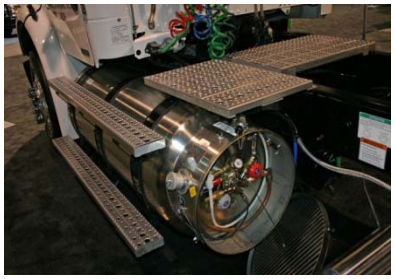
US Hybrid: Plug-in Hybrid Natural Gas Drayage Truck Demonstration

Project Overview

- Demo of 80,000 GVWR Nat Gas Plug-in Hybrid Truck
- Utilizes ISL-G (8.9 L) CARB certified engine and 100 kWh Li-Ion Battery-Pack

Potential Benefits

- Eliminates frequent periods of idling typical at Port facilities where drayage trucks often queue for long periods.
- Hybrid truck will operate in electric mode (EV mode) around 25% of time (30 miles) in charge depletion mode, then in hybrid mode with sustaining charge.
- No limitation of the range and usage and will have higher number of operating hours than a diesel truck.



Goals & Targets

- Target of 30% fuel reduction due to HEV operation
- Out-perform strict CARB emission standards

Partners

- CEC, US Hybrid, GTI and Freightliner

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RFP to Develop & Demonstrate Near Zero Emissions HD Engines

- SoCalGas, CEC, SCAQMD and SJVAPCD are partnering to fund On-Road Heavy-Duty Development, Integration, and Demonstration of Ultra-Low Emission Natural Gas Engines.
- The RFP emissions targets are:
  - 0.02 grams per brake horsepower-hr (g/bhp-hr) NOx
  - 0.01 g/bhp-hr particulate matter (PM)
  - 0.14 g/bhp-hr hydrocarbon (HC)
  - 15.5 g/bhp-hr carbon monoxide (CO)
- Proposal are due July 24, 2013
- http://www.aqmd.gov/rfp/index.html (RFP P2013-22)

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