# Southern California Gas Company
# Briefing for
# A Business Case for Clean Air
# White Paper Working Group

## Natural Gas Near Zero Emission Technologies
## Near-Zero Emission Natural Gas Opportunities

October 31, 2014

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# Natural Gas Near Zero Emission Technologies

To meet NOx and GHG Emissions Reductions

# Offering Cleaner Solutions for The Mobile Sectors

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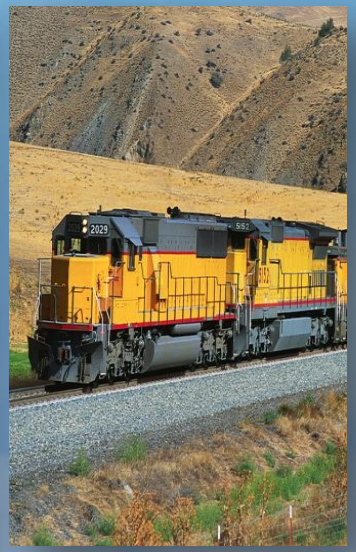
## Current Focus → ← Expanding Focus


Fleet Vehicles

Heavy Duty Trucks


Cargo Handling Equipment

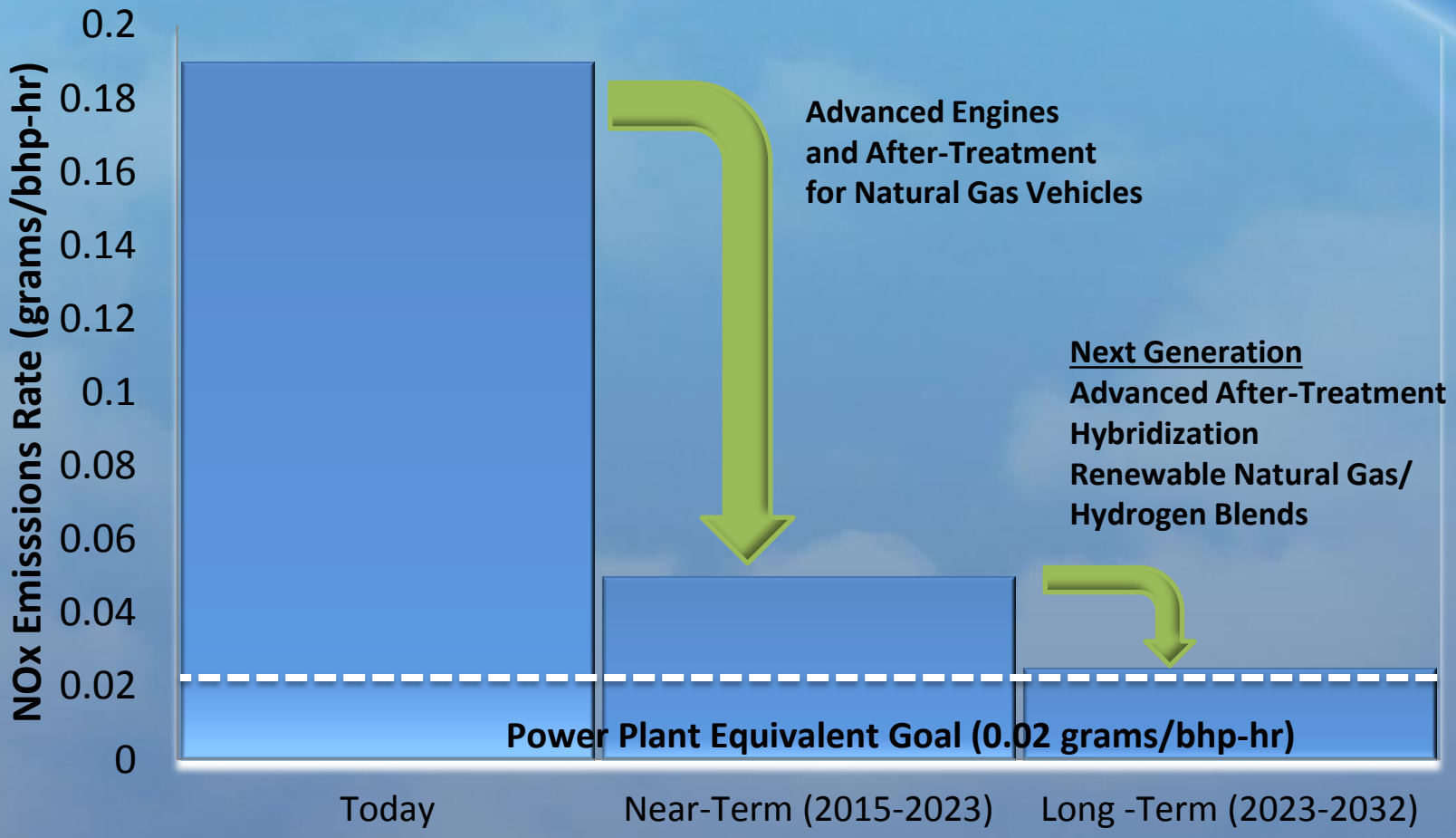



Locomotives

Marine Vessels

## CNG ↔ LNG

# "Near Zero" NOx Emissions for Heavy Duty Truck Achievable through Technology Development



# Technologies Also Address Greenhouse Gas (GHG) Goals

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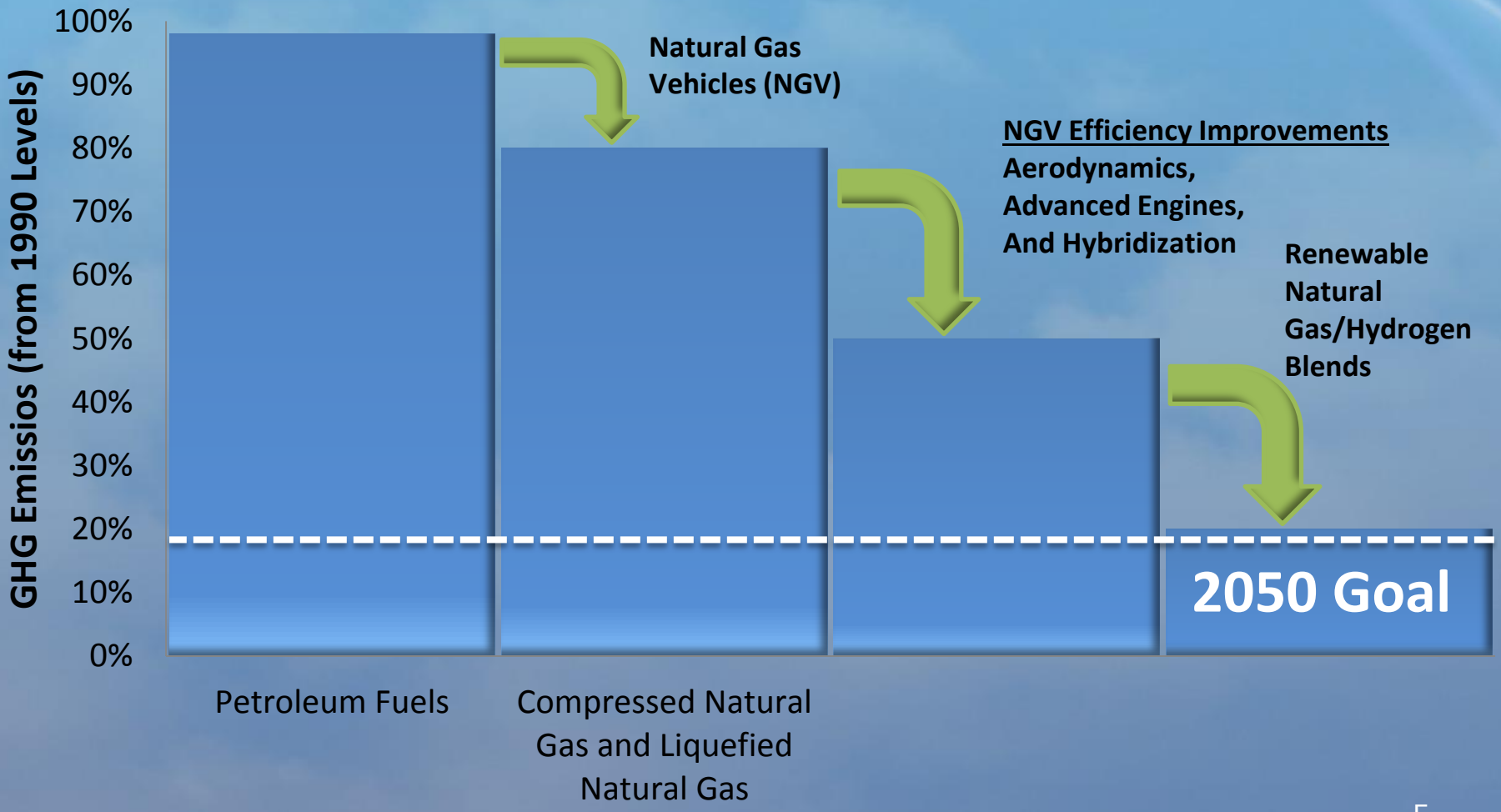
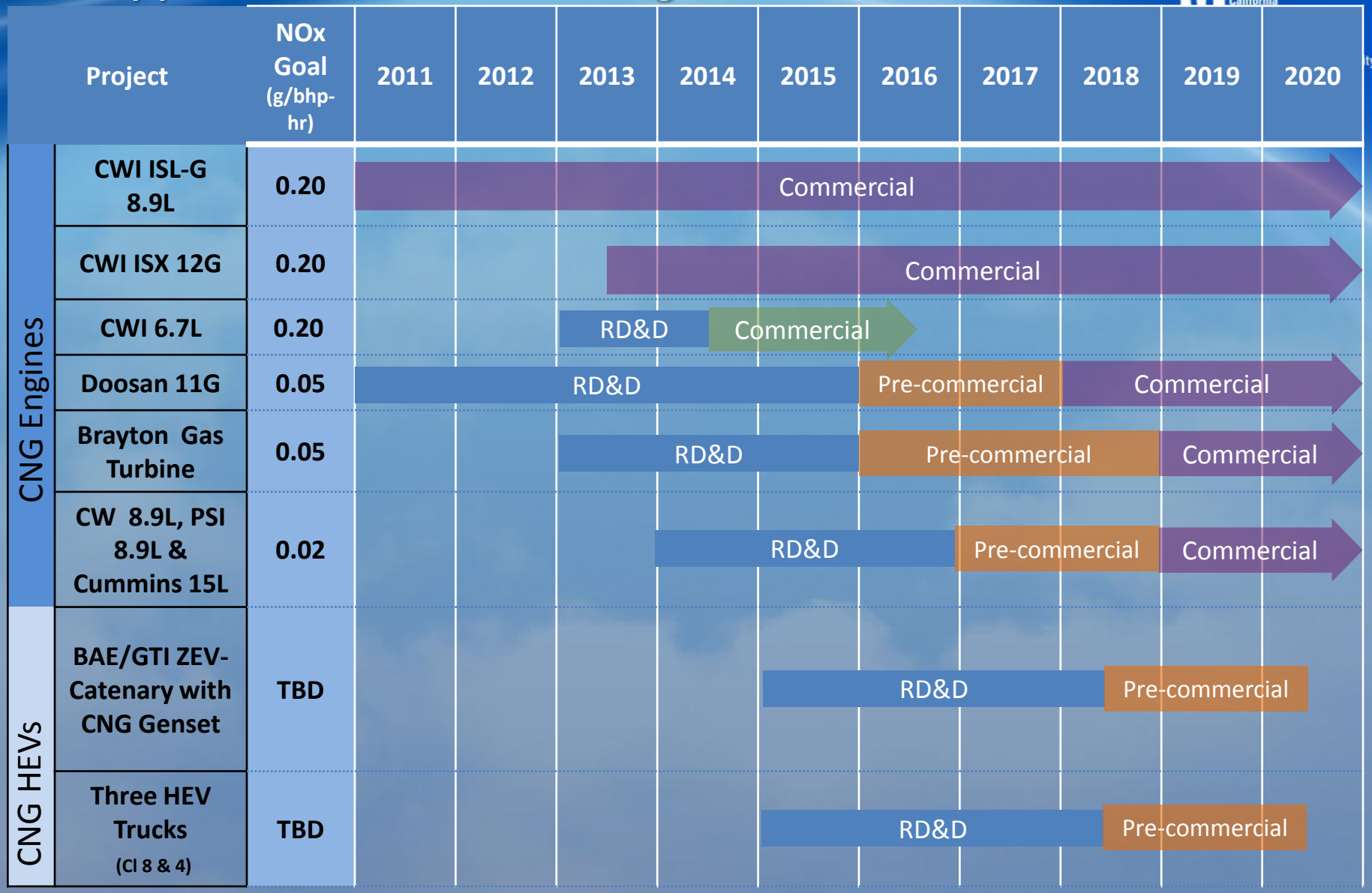
## Efficiency Improvements & Renewables Availability Increase Over Time



# SCG-Supported CNG RD&D Programs for HHD Trucks



# Near-zero Emission Development – CWI8.9L and Cummins 15L Engines

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## *Project Overview*

- Reduce emissions through stoichiometric combustion with high rates of EGR and a three way catalyst to achieve near zero emission (i.e., 90% reduction from current CARB standards) focusing on:
  - dedicated NG engine
  - Power cylinder and cylinder head
  - Air handling (i.e. turbocharger)
  - Ignition system
  - Control system and fuel supply module
- ***Cummins-Westport*** 8.9 liter
- ***Cummins Inc.*** 15 liter


## *Goals / Targets*

- NOx: 0.02 g/hp-hr vs. 2010 0.2 g/hp-hr / PM: near zero
- Performance/Efficiency: 2010 diesel equivalent
- CO2: 15% reduction from current diesel options
- Secondary goal: NH3< 10 ppm

## *Funding Partners*

- CEC ($4M), SCAQMD ($2M), Cummins, SCG ($0.5M)

# ICR-350 Multi-fuel Vehicular Engine

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**Technology Description**

- Develop a near zero emissions dual natural gas and diesel combustor for the existing 350 kW microturbine designed for a hybrid Class-8 trucks
- Use natural gas as a priority, but when the truck is required to travel outside its normal territory or when CNG fueling is not readily available, the engine will seamlessly transition to operate on liquid fuel
- Plan to demonstrate a Kenworth & FedEx Class 8 dual fuel truck in 2015

**Goals / Targets**

- **Price** : Same as emission compliant diesel engine system
- **Fuel Efficiency** : 10-20% savings
- **Maintenance** : 16x longer interval
- **Life** : +1,000,000 miles with only routine maintenance
- **Fuel Flexibility** : any liquid or gas
- **Emissions** : 5x-10x better CARB & no treatment
- **Size** : half size/half weight (+ aerodynamics)
- **Any drivetrain** : mechanical/electric/hybrid

**Funding Partners**

- Brayton, CEC

# US Hybrid: Plug-in Hybrid Drayage and Hybrid Natural Gas Trucks

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## Technology Description

### PHEV

- Demo of 80,000 GVWR Nat Gas Plug-in Hybrid Drayage Truck
- Utilizes CWI ISL-G (8.9 L) CARB certified engine, 100 kWh Li-Ion Battery-Pack, 500 HP Electric Drive Motor, 300 amp converter
- 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.

### Hybrid

- 8.9L CWI ISL-G engine integration with 200kW motor, battery storage and engine controllers

## Goals & Targets

- Low NOx plus target of 30% fuel reduction due to HEV operation
- Overcomes perceived issue of lack of power from CWI 8.9 liter engine currently in use.
- No limitation of the range and usage and will have higher number of operating hours than a diesel truck.
- CNG / LNG / biomethane capable

## Funding Partners

- PHEV - CEC ($1.6M), GTI, US Hybrid, CWI, Calko Transport, Freightliner, UC-Riverside, SCG (two trucks)
- Hybrid – CEC($900K) US Hybrid, SCG ($100K)

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# GTI Class 8 CNG- Hybrid

## Technology Description

- Develop a Class 8 CNG-hybrid truck with an advanced systems approach to NOx reduction.
- Utilize a 9 Liter CWI ISL-G Engine integrated with a 200 kW electric motor, battery storage and engines controls optimized for hybrid operations
- Reduce the NOx emissions beyond current CARB limits
- Showcase the economic attractiveness of CNG vehicles for fleet operators

## Goals / Targets

- Demonstrate improved fuel economy
- Demonstrate ability to meet and exceed CARB emissions limits
- Test the vehicle in a typical duty cycle
- Prepare a Chassis Dynamometer Demon Report with recommendations for extended field testing by a fleet operator as well as summaries of the emissions and fuel economy profiles

## Funding Partners

- CEC ($900K), US Hybrid (In-Kind), SCG ($100K)

# Recent Project Funding by SCAQMD and SoCalGas

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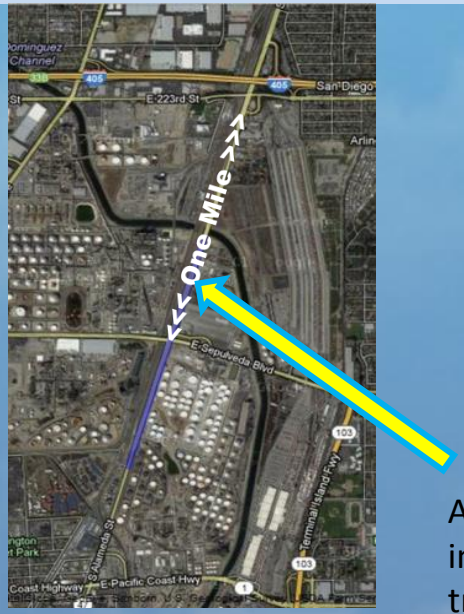
## Gas Technology Institute Team – Electric Drayage Truck with CNG 6.7L Genset Range Extender




Based on Kenworth Model T-370 (Cummins 6.7L CNG engine)

Approx. one mile each way along Alameda St in Carson (current north bound route for trucks to warehouses and I-405)

| Scope | Develop HEV truck with CNG 6.7L engine and Siemens pantograph hardware enabling catenary connection capability. ZEV operation in port, catenary power outside of port, onboard CNG engine genset providing extended range when off of catenary. |
|---|---|
| Schedule | 1/1/15 (Project Start) thru 7/31/18 (Commercialization Roadmap) |
| Budget | Total of about $10M (DOE & SCAQMD 50/50 cost share) – SoCalGas contributing $0.5M in total to SCAQMD share of $5M |
| Benefit | Demonstrates zero-emissions capability of heavy duty truck with extended range provided by CNG and hybrid-electric technology; breaking new “ground” |

# Infrastructure - Central

- Standardized station designs
- Increased dispensing efficiencies
- Better controls, including for time-fil
- Smaller footprint
- Lower cost
- Co-Locating with Hydrogen Station
- On-site Hydrogen Production (SMR)



# Fuel Storage




Need:

- Lower Cost
- Lower Pressure
- Less/Conforming Space

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# Rail & Marine Opportunities for Natural Gas

# Extending the Pathways to Off Road Locomotives

| Today | 2013-2015 | 2015-2023 | 2023-2032 | 2032+ |
|---|---|---|---|---|

**Existing Tier 2 Locomotive**
•5.5 g NOx

- **New engine options (HPDI, dynamic gas blending)**
- **LNG Tender Car**

- **Tier 2 LNG Retrofits (<**3 g NOx)
- **Tier 4 LNG Newbuilds** (<1.3 g NOx)

**Solid Oxide Fuel Cell Technology**

**Near Zero Emissions Target**

**Renewable NG blending**

**NZ-Emission Natural Gas Fuel Cell Locomotive**
•<0.02 g NOx
•>60% efficiency

**Ongoing RD&D for LNG fuel systems and engine conversions**

**Benefits**
- Tier 2: 45% NOx reductions
- Tier 2 and 4: 20% GHG reductions vs Tier 2 diesel


**Benefits***
- 98% + NOx reductions vs Tier 2 diesel
- 55%+ GHG reductions vs Tier 2 diesel w/o RNG

# GE Dual Fuel – Development Timeline

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SCE Testing

Feasibility Study
Optimize In-cylinder combustion
Maximize gas substitution rate
Initial knock detection investigation

Multi-cylinder testing

Detailed performance mapping (HPDI)
Knock detection / mitigation strategy
Maximize gas usage and thermal efficiency

Engine hardware test
DOC development
Control optimization



Two Locomotives Entering Actual Revenue Service (BNSF in Barstow, Ca.)

Real world application
Emissions validation
Tender interface development
Train handling
Engine control interaction
Infrastructure/Fueling logistics

2012 | 2013 | 2014 | 2015…

# Extending the Pathways to The Ports LNG for Marine Vessels

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| Today | 2013-2015 | 2015-2018 | 2018-2023 | 2032+ |
|---|---|---|---|---|

**Existing Tier 1 & 2 Vessels**

- **1,000 ppm fuel sulfur limit for marine vessels in ECAs**
- **IMO Tier 3 NOx standards**

- **Tier 1& 2 LNG retrofits**
- **Tier 3 LNG new builds**
- **First LNG work boats, ferries, short sea shipping vessels deployed**

**Tankers**

**Container Ships**

**Tug boats (new builds)**

**Expanded LNG bunkering**

**Vessel hydrodynamics**

**Vessel size increases**

**High penetration of LNG into marine vessel fleet – estimated at 10,000+ vessels**

**•Ongoing RD&D for LNG fuel systems and vessel retrofits.**
**•Development of LNG bunkering standards and infrastructure**

**Benefits**
- Up to 90% NOx reductions
- 98%+ PM and SOx reductions
- 20%+ GHG reductions

**Benefits**
- **NOx, PM, and SOx reductions beyond IMO Tier 3**
- **GHG reductions of up to 70%**



# Summary

- Engine technology advancements can achieve power-plant equivalent / near-zero emission NOx levels and diesel equivalent GHG emissions reductions
- Pure economics of transportation fuel will drive natural gas technology adoption by the heavy-duty trucking sector
- Near term and consistent financial and other incentives can accelerate and increase the adoption of conventional natural gas technologies
- New storage technologies will have tremendous impact on CNG for both heavy and light duty vehicles
- In-use mobile emissions need further evaluation
- Significant opportunities exist for natural gas trucks and buses, but also for both locomotive and large marine engine emissions reductions

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ENVIRON

# Near-Zero Emission Natural Gas Opportunities in the South Coast Air Basin

Lee Wallace
Southern California Gas

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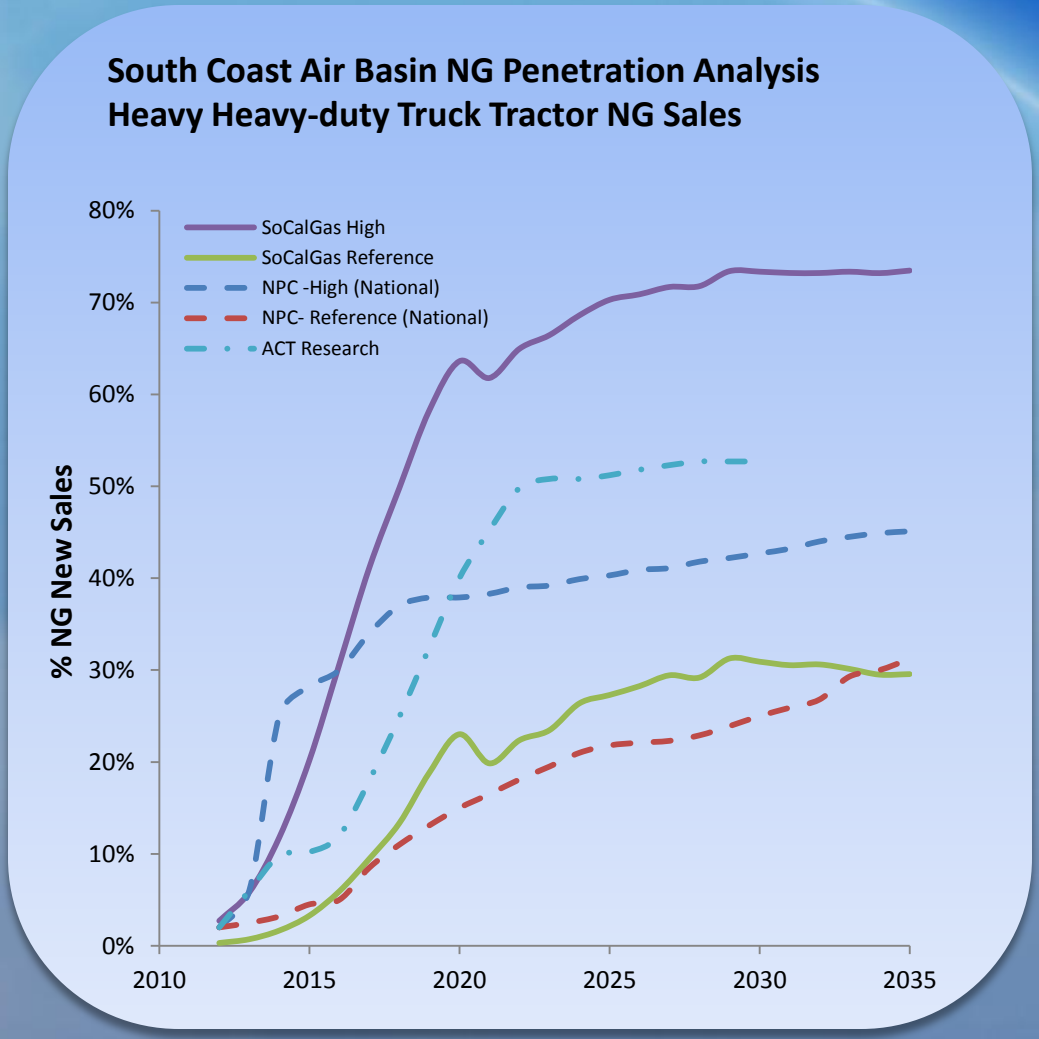
# Project Goals

1. Evaluate NOx benefits of near-zero natural gas engines in heavy-duty vehicles.

2. Explore the effect of incentives on natural gas vehicle penetration rates.

# Economic Analysis via the "NPC Model"

- **Economically Derived Analyses** are required to project NGV new sales (penetration rate) based on competition with diesel technology
- **National Petroleum Council Future of Transportation Fuels Economic Decision Model ("NPC Model")** was used to determine rates of NGV adoption by the open market
- **NPC Model Projections** are consistent with projections published by independent research organizations
- **SoCalGas Adjustments** are made to the NPC Model settings specific to the South Coast Air Basin marketplace
- **SoCalGas "Reference" and "High"** NGV adoption curves via the NPC model are derived to bound the analysis



# Economic Analysis via the "NPC Model" (cont'd)

- **Fuel Price Projections** are based on 150% of EIA 2010 projections
- **Model variables** adjusted for SoCalGas scenarios include *natural gas vehicle cost* and the *natural gas adoption curve* (3 settings, aggressive, moderate, conservative)
- **SoCalGas Reference Penetration Rate** case ("SoCalGas Reference") assumes: (1) a high price differential between NGV and Diesel Trucks; and (2) uses the conservative NGV adoption curve
- **SoCalGas High Penetration Rate** case ("SoCalGas High") assumes: (1) a low price differential between NGV and Diesel Trucks; and (2) uses aggressive NGV adoption curve
- **NG Financial Incentives** are applied to increase NGV new sales projections

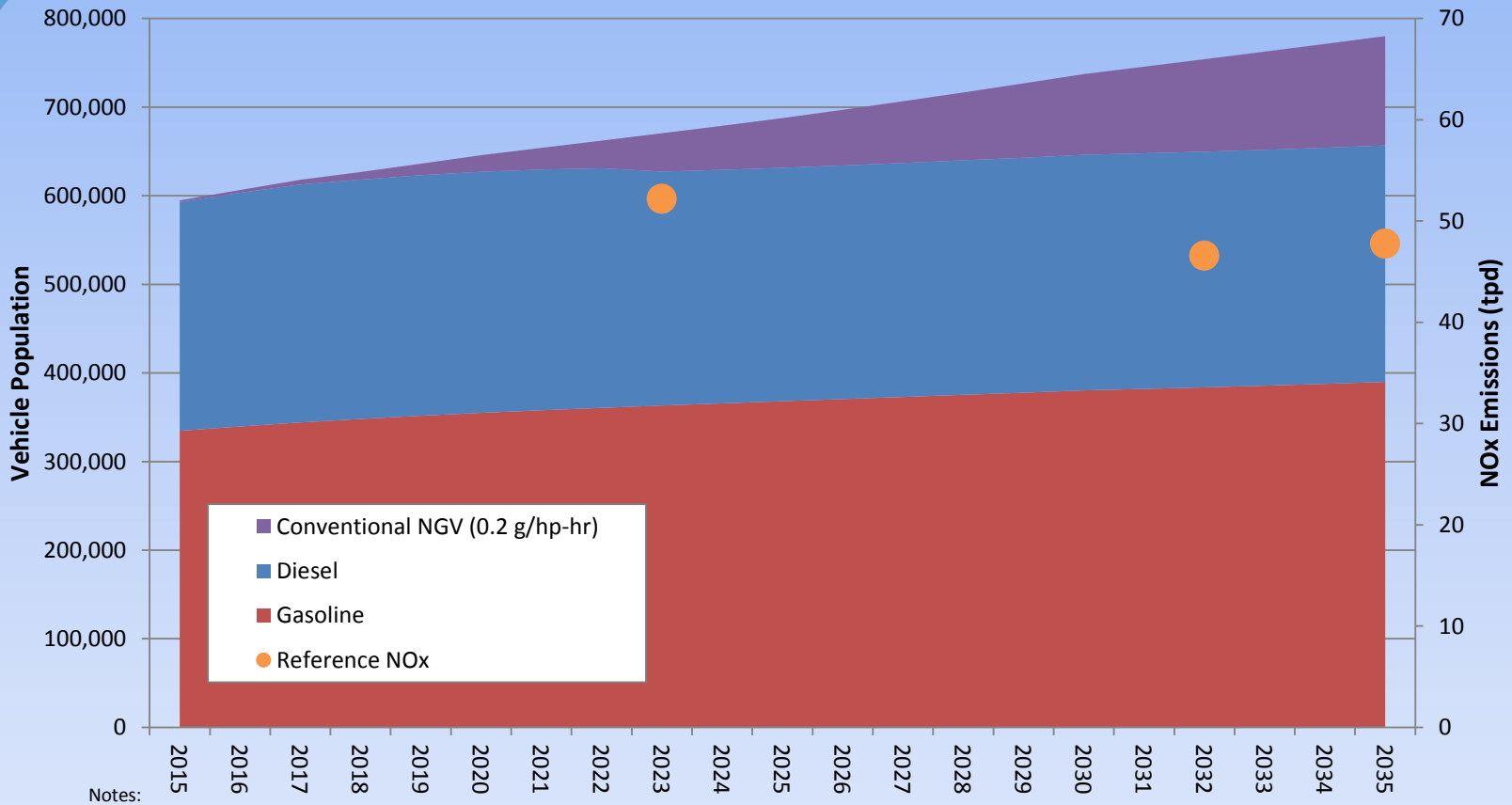
**SoCalGas NPC modeled cases, NG truck pricing assumptions.**

| Truck Group | 2023 Base Diesel Vehicle Cost | NG Incremental Price in 2023 | |
|---|---|---|---|
| | | SoCalGas Reference | SoCalGas High |
| Class 7/8 Combination | $144,953 | $47,355 | $30,028 |
| Class 7/8 Single | $ 190,399 | $18,906 | $7,463 |
| Drayage | $144,953 | $34,604 | $18,399 |
| Refuse | $190,399 | $18,906 | $7,463 |
| Class 3-6 | $61,529 | $21,165 | $15,682 |

# SoCalGas High- BASE CASE

## In-state Heavy-duty Truck Fleet Composition [1]

## – No Incentives -



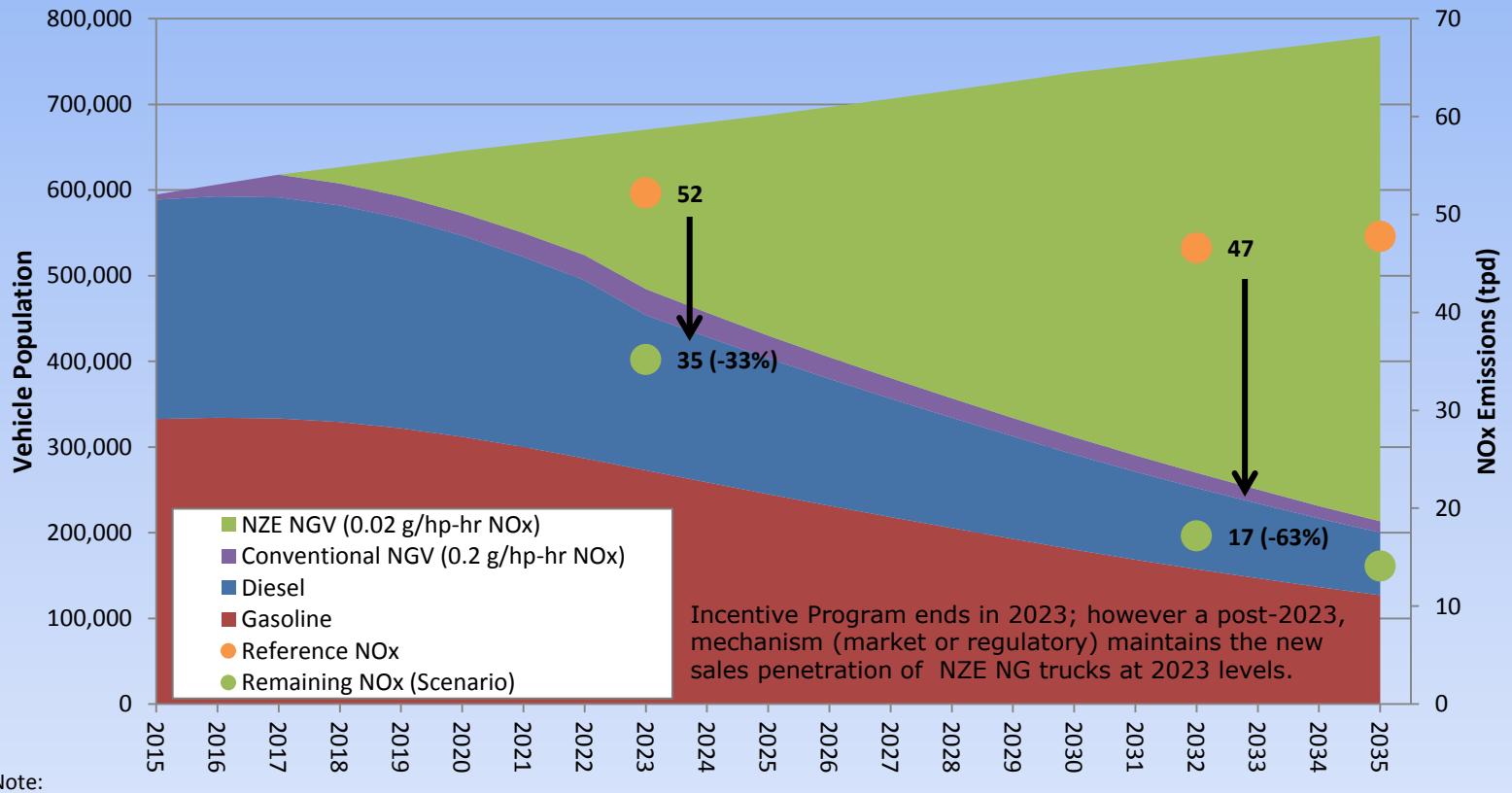

Notes:

1. Analysis includes T7 Drayage, T7 Single, T7 Solid Waste Collection Vehicle, T7 Tractor, T7 Tractor Construction, T7 Agriculture, T7 Single Construction, T7 Public, T7 Utility, T7 IS, T6 Instate Heavy, T6 Instate Small, T6 Utility, T6 Public, T6 TS, T6 Agriculture, T6 Instate Construction Heavy, T6 Instate Construction Small, LHDDT, and LHDGT.
2. Vehicle population is based on the EMFAC2011 data for the South Coast Air Basin.
3. Reference NOx emissions were obtained from the 2012 Air Quality Management Plan (AQMP) from the SCAQMD.

# SoCalGas High Incentive Scenario

## In-State Heavy-duty Truck Fleet Composition [1]

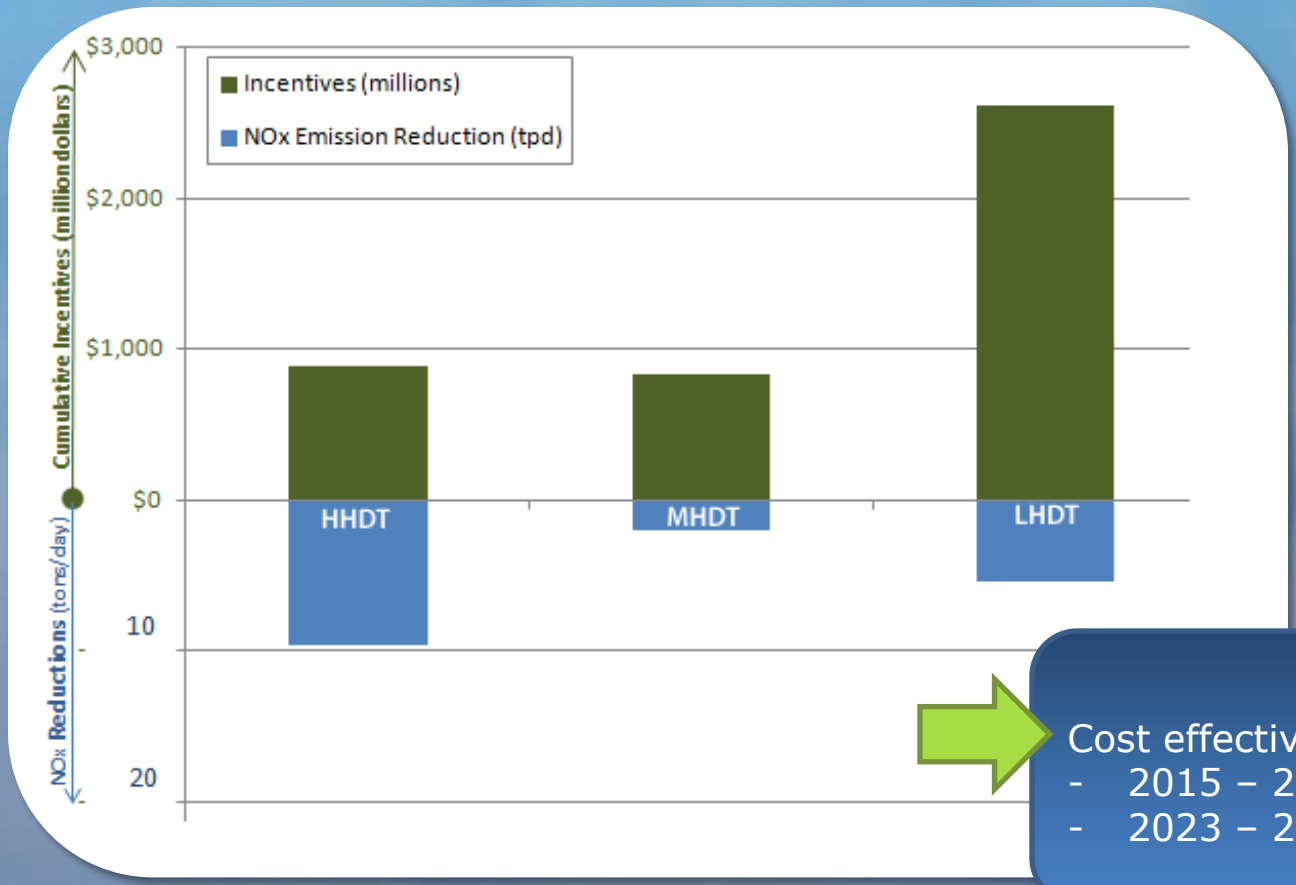
## - MODIFIED Maximum Incentivized[2] NG Truck Purchases -




Note:

1. Analysis includes T7 Drayage, T7 Single, T7 Solid Waste Collection Vehicle, T7 Tractor, T7 Tractor Construction, T7 Agriculture, T7 Single Construction, T7 Public, T7 Ut T7 IS, T6 Instate Heavy, T6 Instate Small, T6 Utility, T6 Public, T6 TS, T6 Agriculture, T6 Instate Construction Heavy, T6 Instate Construction Small, LHDDT, and LHDGT.
2. Maximum incentives range from $15,500 - $35,000/Truck depending on the vehicle type and engine size
3. Assumed penetration rates after the incentive period ends remain at the 2023 level due to some mechanism.

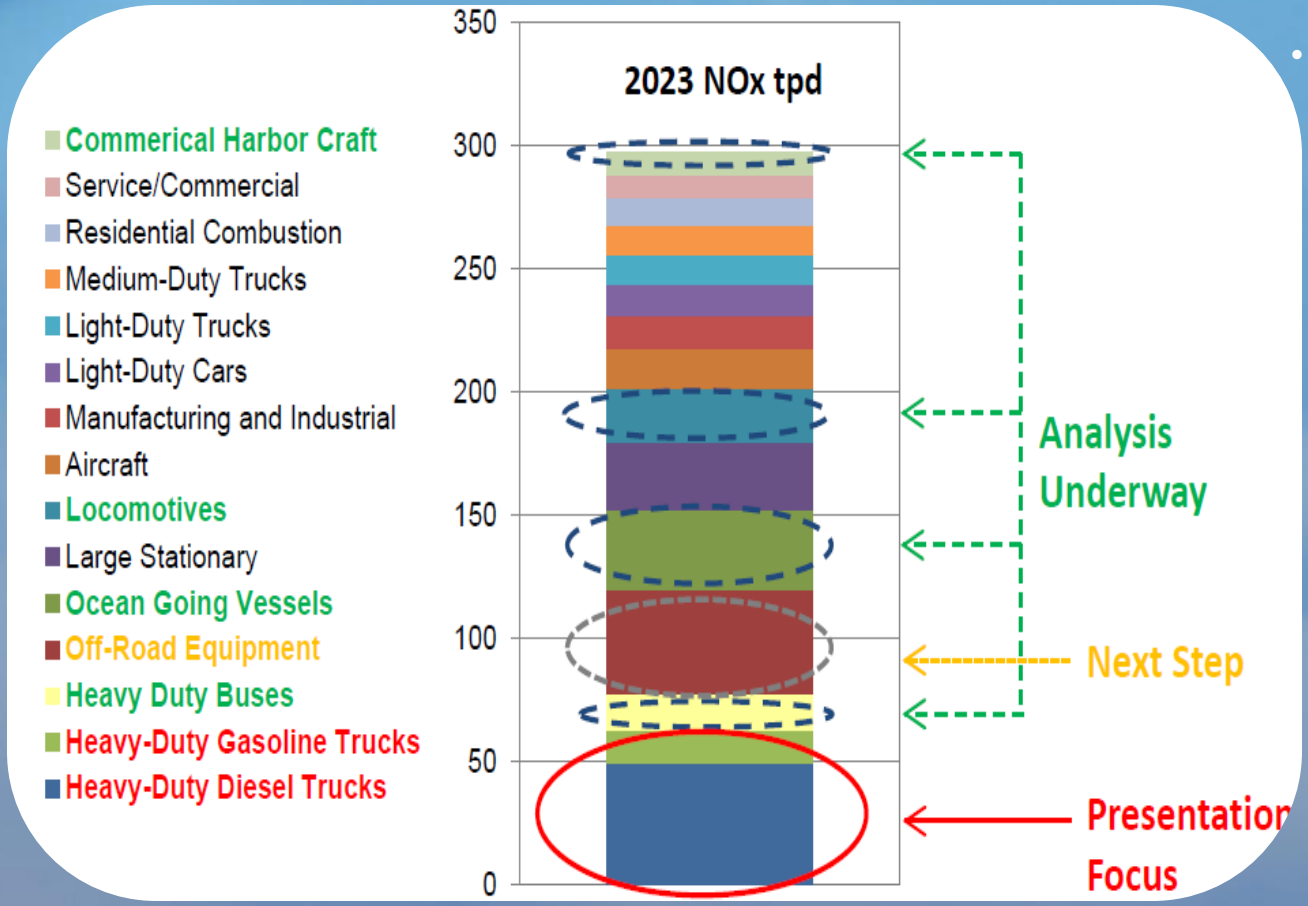
# SoCalGas High Incentive Program
## 2023 Cumulative Cost vs. NOx Reductions




**Next Step**

Cost effectiveness/ranking for sources
- 2015 – 2023 (incentive program)
- 2023 – 2035 (regulatory program)

# Technical Analyses: Next Steps




- Expand analyses to other on- and off-road mobile sources

Conduct full cost-effectiveness analyses (beyond cost vs. year-specific emission reductions) by source categories

Step-wise incentives (0.1 g/bhp-hr from 2015-2018 and 0.02 g/bhp-hr from 2018+)

# Summary

- Pure economics of transportation fuel will drive natural gas technology adoption by the heavy-duty trucking sector.
- Financial incentives can accelerate and increase the adoption of conventional natural gas technologies.
- Additional financial incentives (<$10K/vehicle) can shift conventional natural gas technology purchases to "NZE" (90% NOx reductions) natural gas purchases.
- Maximized NOx reductions can be achieved through post-incentive period mechanisms (TBD) to maintain NZE natural gas vehicle penetration rates.