NREL
NATIONAL RENEWABLE ENERGY LABORATORY

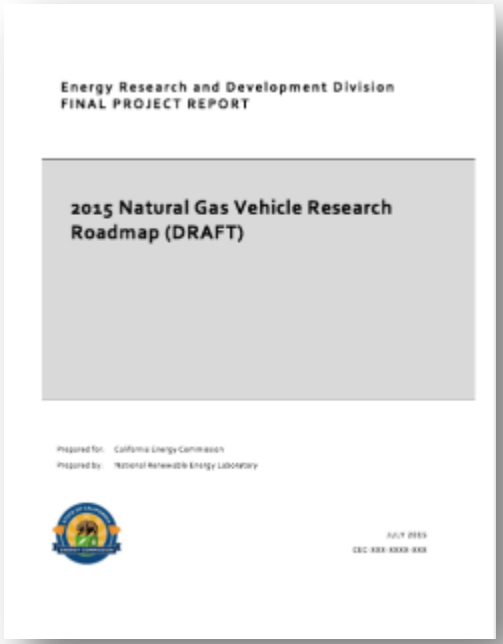
2015 CEC Natural Gas Vehicle Research Roadmap Update

Natural Gas Vehicle Technology Forum

Alex Schroeder
National Renewable Energy Laboratory
October 20, 2015

CEC NGV Roadmap Overview and Objectives

Objective: Inform natural gas vehicle R&D investment decisions made by the California Energy Commission (CEC) and stakeholders to promote increased ratepayer benefits



NGVRR 2009

Developed in 2008-2009 to provide "most needed, major natural gas vehicle related research, development, demonstration, and deployment" in the following areas:

- Engine development and vehicle integration actions
- Fueling infrastructure and storage actions
- Technical and strategic studies actions

NGVRR 2015

Updates previous NGVRR to:

- Identify emerging R&D opportunities
- Identify fundamental changes in the NGV market and associated technologies
- Reassess the priority of previously identified technologies given developments to develop a "new baseline".

Guiding Direction and Legislation

Senate Bill 1250 (2006)

Enables Natural Gas Research funds to be used for advanced transportation technologies that reduce air pollution and GHG emissions beyond applicable standards as a benefit to natural gas ratepayers

Assembly Bill 1007 (2007)

Directed CEC to develop a State Alternative Fuels Plan. Plan presents strategies and actions California must take to increase the use of alternative transportation fuels including natural gas

Assembly Bill 32 (2006)

Calls for approximately 36% of the state's 2020 GHG reduction targets to come from the transportation sector

Assembly Bill 118 (2007)

Created the California Energy Commission's Alternative and Renewable Fuel and Vehicle Technology Program to deploy alternative and renewable fuels and advanced transportation technologies

Senate Bill 1204 (2014)

Created the California Clean Truck, Bus and Off-Road Vehicle and Equipment Technology Program to fund zero and near-zero emission truck, bus, and off-road vehicle and equipment technologies and related projects

2015 CEC NGV Research Roadmap Process

May 2014	Literature Review, Initial Outline Developed and Stakeholder Outreach Initiated
August 2014	Development of Conceptual Draft
October 2014	Presentation of Conceptual Draft at 2014 NGVTF
December 2014	Outreach to Stakeholders to Review Conceptual Draft
June 2015	Presentation of Final Draft to CEC for Review
October 2015	Presentation of Final Draft at 2015 NGVTF
Fall 2015	Final Draft NGVRR Released and Public Workshop (Tentative)
Spring 2016	Final NGVRR Released

2015 CEC NGV Research Roadmap

2015 NGVRR Core Components

Review of Market and Technology Changes 2009-2014

NGV R&D Gaps and Market Barriers

Prioritization of R&D Recommendations

NGV Market and Technology 2009-2014

Significant Increases in Natural Gas Reserves and Production Projections Have Created Downward Pressure on Prices While Crude and Gasoline Prices also Have Decreased

U.S. Natural Gas Citygate Price ($/gge)

Source: U.S. Energy Information Administration

WTI crude oil futures price

10/15/2015: **$46.38/bbl**

Down $35.40 from year earlier

Natural gas futures price

10/15/2015:

$2.453/mmBtu

Down $1.347 from year earlier

Retail gasoline price (West Coast PADD)

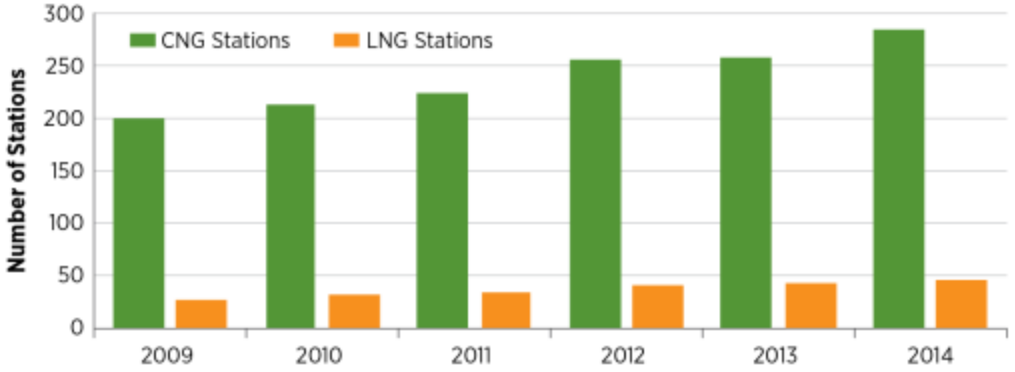
10/12/2015: **$2.748/gal**

Down $0.788 from year earlier

NGV Market and Technology 2009-2014

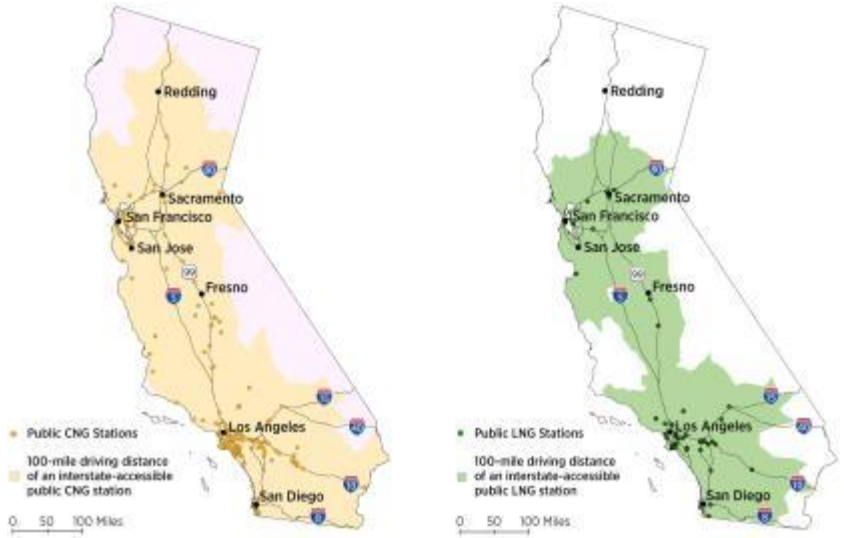
Steady Growth in Natural Gas Infrastructure Growth and Distribution

In 2009, there were 191 CNG stations and 25 LNG stations in CA. By 2014, this number increased to 284 and 46, respectively.



Source: U.S. Department of Energy Alternative Fuel Data Center

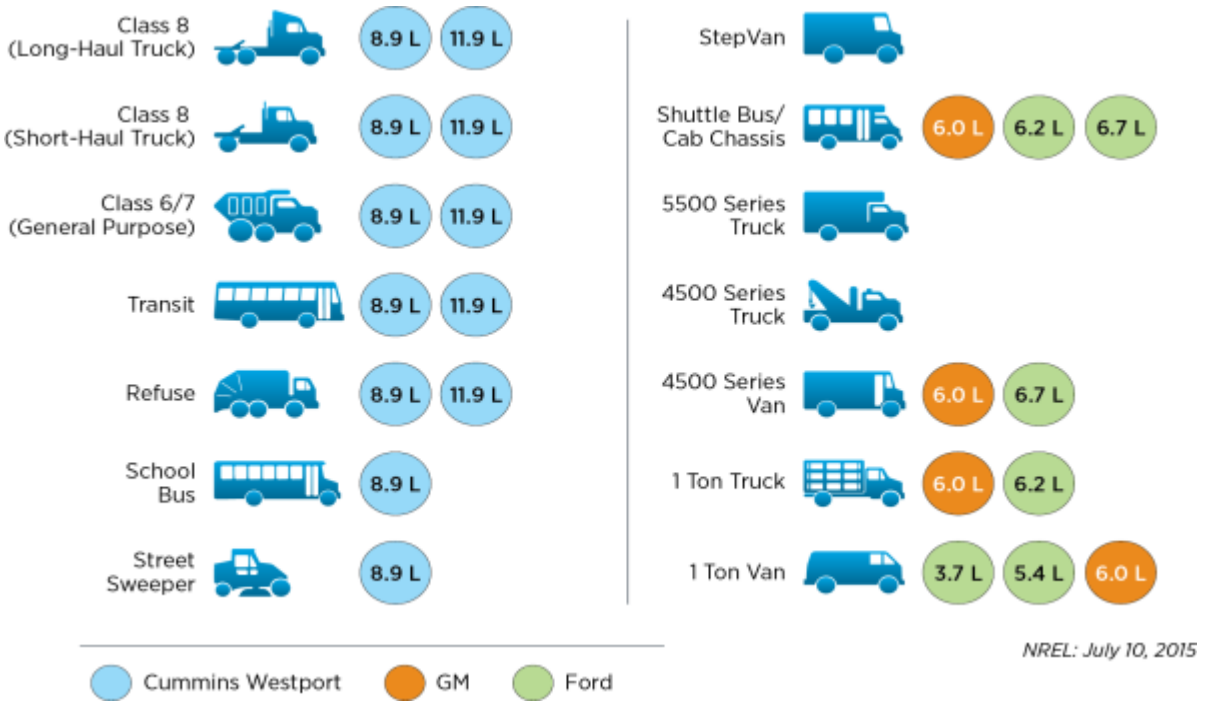
- Widespread public access to CNG for highway travel
- Robust CNG infrastructure in greater Los Angeles area
- Limited public availability of LNG



Source: U.S. Department of Energy Alternative Fuel Data Center

NGV Market and Technology 2009-2014

Improvements in OEM Availability for MD/HD



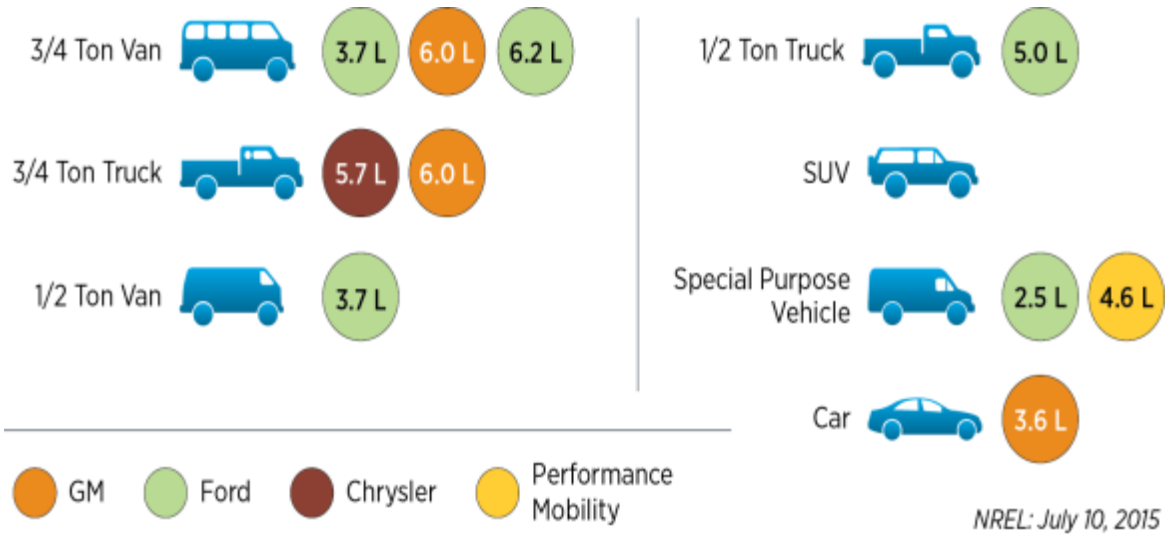
CWI 6.7L engine is in trial phase with deployment scheduled for 2016

Development of several large displacement engine have been postponed or cancelled

This chart represents the author's best estimate of vehicle and engine availability as of the anticipated date of final report publication and may be subject to further refinement prior to that date.

NGV Market and Technology 2009-2014

Light-Duty Market is Increasingly Aligning Towards Fleets



Honda announced that it is discontinuing CNG Civic

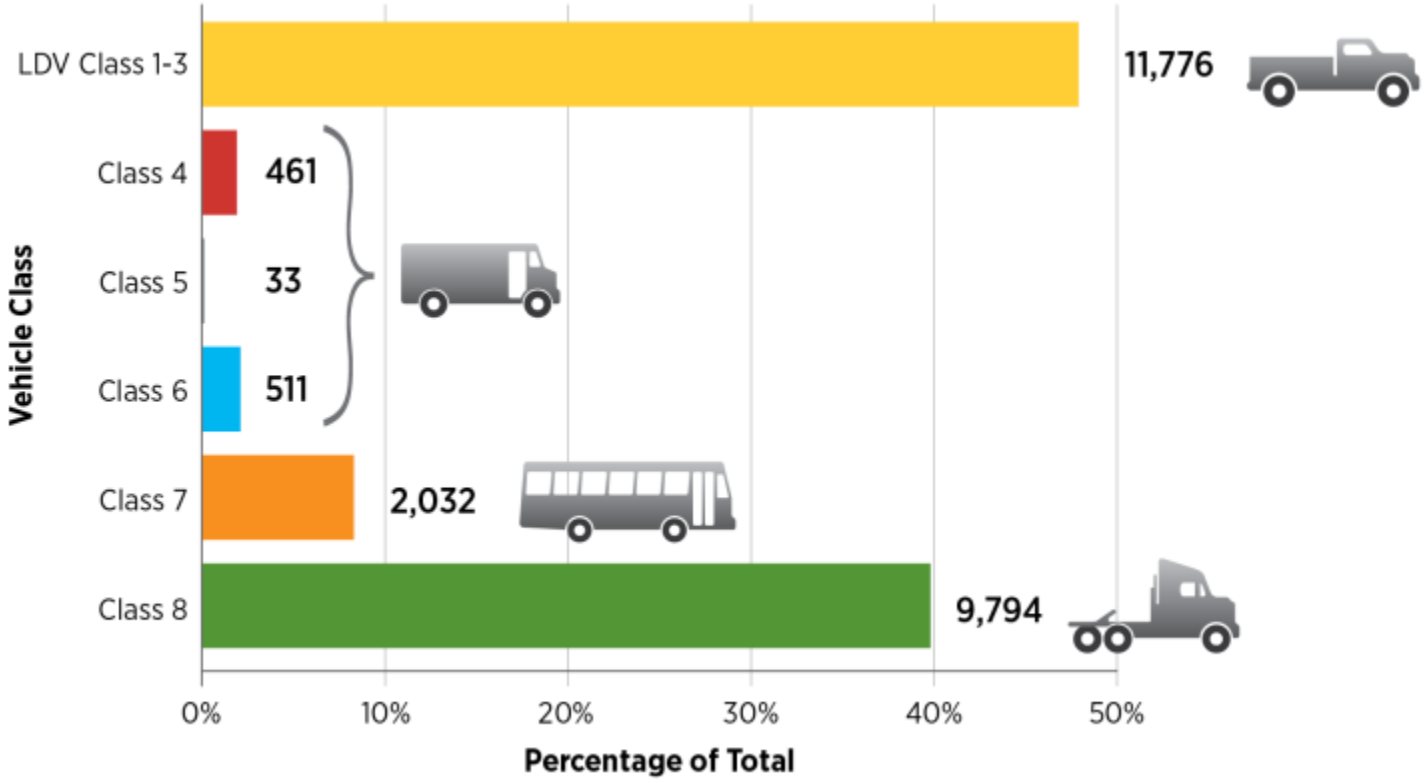
Chevrolet Impala release has been delayed

Ford announced availability of CNG 5.0L engine for new F-150

This chart represents the author's best estimate of vehicle and engine availability as of the anticipated date of final report publication and may be subject to further refinement prior to that date.

NGV Market and Technology 2009-2014

NGV Adoption Favors LD and HD NGVs, Less So MD



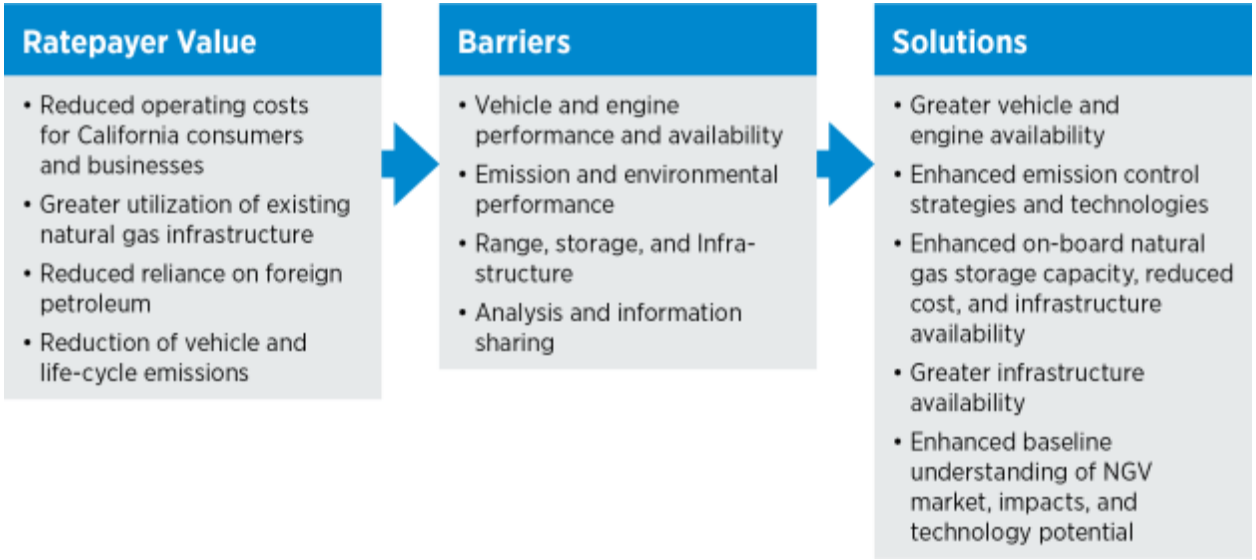
*Does not include third-party conversions

NGVRR 2015 Recommended R&D Priorities

NGVs have a significant opportunity to create and increase ratepayer value by leveraging abundant, low-cost natural gas

Key changes between 2009 and 2014 include:

- A growing, stable, market for natural gas production and use
- Increased natural gas engine availability, performance, and reliability
- Significant regulatory and policy developments that increase requirements for emission reductions
- Performance and efficiency gains in conventional vehicle technologies



NGVRR 2015 Recommended R&D Priorities

Innovation is Needed to Maintain Momentum and Increase Ratepayer Benefits

Natural gas vehicle technology, features, and performance will need to experience significant levels of innovation to keep up with incumbent and emerging technologies and meet future regulations including the following:

- Decrease the cost of on-board natural gas storage and increase vehicle integration of storage
- Increase natural gas engine and vehicle availability, improve efficiency and maintain similar performance characteristics to gasoline and diesel alternatives.
- Advance technologies that continue to reduce NOx and greenhouse gas emissions.
- Continue supporting current, accurate, and timely information on natural gas vehicle technologies and availability.
- Continue coordination and collaboration between and among California and federal agencies with natural gas vehicle stakeholders to adapt to changing markets, customer needs, and technology developments.

NGVRR 2015 Recommended R&D Priorities

Range, Storage, and Infrastructure — R&D Objective: *Enhanced on-board natural gas storage capacity, reduced cost, and infrastructure availability*

	Short (0–1 year)	Medium (1-5 years)	Long (5-10 years)
Increase Natural Gas Storage and Enhance Vehicle Integration			
Investment Needed: ***>$1 million*** Priority/Impact: ***High***	• Identify technologies, strategies, and barriers to improve CNG storage integration	• Underwrite cost of vehicle design and engineering for better CNG storage integration • Initial vehicle models become available	• Incorporate low pressure natural gas storage into vehicles • Enable large-scale integration of compressed gas cylinders into vehicle designs
Develop Low-Cost Carbon and Glass Fiber Storage			
Investment Needed: ***>$1 million*** Priority/Impact: ***High***	• Identify collaboration opportunities with the National Network for Manufacturing Innovation	• Fund dedicated research center(s) for the development of low-cost manufacturing of lightweight gas storage cylinders • Certify and integrate advanced fiber-based storage vessels into vehicles	• Develop bio-based materials for storage containers
Maximize Cylinder Utilization and Improve Fill Quality			
Investment Needed: ***$1 million*** Priority/Impact: ***High***	• Develop algorithms in fueling dispensers and on-board vehicles to adjust for temperature changes during fueling to ensure a greater fill	• Conduct research on sensor, pressure relief devices, and valve technologies that can enable greater CNG fill capacity	

NGVRR 2015 Recommended R&D Priorities

Range, Storage, and Infrastructure — R&D Objective: *Enhanced on-board natural gas storage capacity, reduced cost, and infrastructure availability*

	Short (0–1 year)	Medium (1-5 years)	Long (5-10 years)
Develop Low-Pressure, High-Density Natural Gas Storage Vessels			
Investment Needed: ***>$1 million*** Priority/Impact: ***Medium***	• Complete ARPA-E projects to allow for further technology assessments	• Resolve fuel compatiability and durability issues with adsorbents.	• Enable commercially viable adsorbent storage as multiple performance targets are met • Begin to integrate commercially viable adsorbent storage products into vehicles
Develop Small or Modular Fueling Facilities			
Investment Needed: ***>$1 million*** Priority/Impact: ***Medium***		• Develop small-scale (1-5 vehicles) refueling facility technologies • Develop modular fueling infrastructure technology that can be scaled as demand increases	
Promote "Smart" Cylinders and Refueling Stations to Enhance Monitoring Capabilities			
Investment Needed: ***$1 million*** Priority/Impact: ***Medium***		• Develop algorithms, sensing, and communications technology in fueling dispensers, natural gas storage containers, and vehicles to communicate critical operating and safety information. • Some of these technologies may also enhance fill quality as noted previously	

NGVRR 2015 Recommended R&D Priorities

Range, Storage, and Infrastructure — R&D Objective: *Enhanced on-board natural gas storage capacity, reduced cost, and infrastructure availability*

	Short (0–1 year)	Medium (1-5 years)	Long (5-10 years)
Develop Certification Procedures for Natural Gas Conformable Storage Tanks			
Investment Needed: ***<$1 million*** Priority/Impact: ***Low***		• Identify protocols needed for conformable tank certification • Develop technology and procedures for conformable tank certification	
Develop Cost-Effective Home Refueling Technologies			
Investment Needed: ***>$1 million*** Priority/Impact: ***Low***		• Develop home refueling technologies that can be cost competitive with home electric vehicle charging	
Increase Fueling Station Operational Efficiency			
Investment Needed: ***<$1 million*** Priority/Impact: ***Low***	• Fund and identify opportunities for greater fueling infrastructure efficiency via on-site storage and improved operation		

NGVRR 2015 Recommended R&D Priorities

Vehicle and Engine Performance and Availability — R&D Objective: *Greater Vehicle and Engine Availability*

	Short (0–1 year)	Medium (1-5 years)	Long (5-10 years)
Continue Research in Medium- and Heavy-Duty Engine Development			
Investment Needed: ***>$1 million*** Priority/Impact: ***High***	• Assess R&D and market needs for LNG engines in heavy-duty applications given recent delays	• Continue the development of low NOx engines and technologies such as exhaust gas recirculation, ignition, and fuel injection • Continue integration of engines into medium- and heavy-duty vehicle applications • Pursue R&D in medium- and heavy-duty natural gas engines that can reduce fuel economy penalties relative to diesel	• Support the development of HCCI and RCCI engines to ensure that they are compatible with natural gas and provide comparable or superior performance to diesel
Invest in Light-Duty Engine Development and Direct Injection Engines			
Investment Needed: ***>$1 million*** Priority/Impact: ***Medium***	• Identify needs for additional engines and emission controls when using natural gas in high-efficiency engines	• Develop solutions for natural gas to be used in direct injection engines such as fuel injection and ignition technologies • Underwrite costs to develop additional high-efficiency natural gas engines such as Atkinson and Miller cycle technology	
Exploit Natural Gas Properties and Address Fuel Quality Discrepancies			
Investment Needed: ***>$1 million*** Priority/Impact: ***Medium***		• Identify optimal control strategies for the operation of natural gas in current engine designs and applications	• Develop clean sheet natural gas engines with specific design and control strategies

NGVRR 2015 Recommended R&D Priorities

Emission and Environmental Performance — R&D Objective: *Enhanced Emission Control Strategies and Technologies*			
	Short (0–1 year)	Medium (1-5 years)	Long (5-10 years)
Promote Further Development of Vehicle Hybridization and Electrification Technologies			
Investment Needed: ***>$1 million*** Priority/Impact: ***Medium***	• Identify niche markets and portions of a given vehicle's drive cycle that would benefit from the hybridization of natural gas powertrains	• Support the incorporation of hybridization technologies into light-, medium-, and heavy-duty vehicle and engine development	
Develop Optimized Emission Controls for Natural Gas			
Investment Needed: ***$1 million*** Priority/Impact: ***Medium***	• Identify current emission profiles for natural gas vehicles	• Fund the development of aftertreatment and emission controls, including methane, that will provided for enhanced emission profiles and more efficient operations	
Address LNG Storage Tank Venting on Vehicles			
Investment Needed: ***$1 million*** Priority/Impact: ***Low***		• Fund research to reduce LNG venting during operations, which may include recirculation, greater insulation, or cooling	

NGVRR 2015 Recommended R&D Priorities

Analysis and Information Sharing — R&D Objective: *Enhanced Baseline Understanding of NGV Market, Impacts, and Technology Potential*

	Short (0–1 year)	Medium (1-5 years)	Long (5-10 years)
Update Emission Data on Natural Gas Vehicles			
Investment Needed: ***$1 million*** Priority/Impact: ***High***		• Conduct vehicle chassis dynamometer testing to compare emission levels between various gasoline, diesel, and natural gas vehicles and engines utilizing drive cycles that represent NGV market opportunities	
Continue and Enhance Coordinated NGV Research and Support the NGVTF			
Investment Needed: ***<$1 million*** Priority/Impact: ***High***	• Continue to leverage the NGVTF as a means to gather stakeholder input and discuss and refine research priorities • Identify opportunities for collaboration with DOE and ARPA-E via funding opportunity announcements and regular program activities	• Explore the inclusion of additional technologies such as marine and rail into the NGVTF • Determine the need to revise and rescope the NGVRR	
Determine the Best Use of Natural Gas in Transportation			
Investment Needed: ***<$1 million*** Priority/Impact: ***Medium***		• Fund a study to look at competing uses for natural gas in the transportation sector in light of policy objectives and elsewhere to determine the best opportunities, applications, or niches for future R&D	

NGVRR 2015 Recommended R&D Priorities

Analysis and Information Sharing — R&D Objective: *Enhanced Baseline Understanding of NGV Market, Impacts, and Technology Potential*

	Short (0–1 year)	Medium (1-5 years)	Long (5-10 years)
Continue to Enhance Publically Available Information on Natural Gas Vehicles			
Investment Needed: ***<$1 million*** Priority/Impact: ***Medium***	• Work with fuel providers, utilities, and natural gas stakeholders to develop a comprehensive and detailed list of natural gas fueling sites in California • Develop better data and mechanisms for collecting data on the resale and repurposing of vehicles to run on natural gas		
Identify Market Impact of Technology Developments			
Investment Needed: ***<$1 million*** Priority/Impact: ***Low***		• Fund a study to quantify the economic and deployment potential of the various technology investments outlined in the NGVRR	

Stakeholder Input Has Been Critical

On behalf of CEC, NREL would like to thank and acknowledge the following organizations for their contributions to the NVGRR development:

Agility

American Honda Motor Co.

Atlanta Gas and Light

California Air Resources Board

California Energy Commission Alternative and Renewable Fuel and Vehicle Technology Program

Clean Vehicle Education Foundation

Cummins Westport

Fiat Chrysler Automobiles

Gas Technology Institute

General Motors

Gladstein, Neandross, and Associates

NGVAmerica

Pacific Gas and Electric Company

Port of Los Angeles

South Coast Air Quality Management District

Southern California Gas Company

U.S. Department of Energy – Advanced Research Projects Agency - Energy

U.S. Department of Energy – Vehicle Technologies Office

Waste Management

Westport

Thank You

Alex Schroeder

alex.schroeder@nrel.gov

Learn more at
www.nrel.gov/vehiclesandfuels
www.nrel.gov/hydrogen