NATURAL GAS VEHICLE RESEARCH ROADMAP

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Abstract

The California Energy Commission's NGVRR identifies initiatives and projects that research, develop, demonstrate, and deploy advanced fuel-efficient natural gas powered transportation technologies and fuel switching strategies that result in a cost-effective reduction of on-road and off-road petroleum fuel use in the short and long term. Research roadmap findings show that there exists a lack of heavy-duty and off-road engines sizes or capacity, and that vehicle integration of new engines is a significant hurdle to greater natural gas vehicle availability and market penetration. Specific research topics include Engine Development and Vehicle Integration, Fueling Infrastructure and Storage and Technical and Strategic Studies.

Keywords: Natural gas vehicles, heavy-duty natural gas engines, natural gas fuel, natural gas fueling infrastructure, low emission trucks, liquefied natural gas transportation fuel.

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CHAPTER 1: Introduction and Summary

California's growing population and economic demands have increased reliance on imported fossil fuels and electricity. Growing demand for petroleum worldwide makes uncertain the state's ability to continue importing petroleum in the long term without incurring greater price and supply instability. At the same time, fossil fuel-based energy use is driving climate change, and the state has established goals for transitioning to lower-carbon fuels over the coming decade. Alternative fuels will play a significant role in addressing both of these issues statewide, and natural gas vehicles (NGVs) have the potential to serve as a viable portfolio element for meeting state petroleum and pollution reduction targets. This *Natural Gas Vehicle Research Roadmap* describes the strategic research, development, demonstration, and deployment (RDD&D) needed to enhance the viability of the NGV market in California.

California Public Policy Context

Assembly Bill 1007 (Pavley, Chapter 371, Statutes of 2005) directs the California Energy Commission (Energy Commission) and the California Air Resources Board (ARB) to "develop and adopt a state plan to increase the use of alternative transportation fuels" in California. In parallel to AB 1007, the Low Carbon Fuel Standard (LCFS)—as initiated under Executive Order S-1-07—calls for a reduction of at least 10 percent in the carbon intensity of California's transportation fuels by 2020. Ultimately, the LCFS analysis will become part of the State Implementation Plan for alternative fuels as required by AB 1007 and adopted by ARB as an "early action" item under the Global Warming Solutions Act (AB 32, Nuñez, Chapter 488, Statutes of 2006) legislation setting greenhouse gas limits for the state. The ARB regulatory process to implement the LCFS is expected to be completed no later than December 2008.

Most recently, AB 118 (Nuñez, Chapter 750, Statutes of 2007) establishes within the Energy Commission the Alternative and Renewable Fuel and Vehicle Technology Program, effectively providing the means to implement recommendations developed under AB 1007. The Alternative and Renewable Fuel and Vehicle Technology Program will fund projects that develop, demonstrate, and deploy both alternative fuel infrastructure and alternative fuel vehicle technology. As directed by AB 118, the new Program emphasizes technology deployment and commercialization and emphasizes support for fuels that "…lead to sustainable feedstocks…." The law also directs the Energy Commission to "create an advisory body to help develop an investment plan to determine priorities and opportunities for the Alternative and Renewable Fuel and Vehicle Technology Program…," and that the plan "shall describe how funding will complement existing public and private investments, including existing state programs that further the goals of this chapter."[1]

These policies call for a portfolio of options to build alternative transportation fuel use in California, and values alternative transportation fuel options that can implemented in the near- and long-term. The Roadmap supports these alternative transportation fuel policies by outlining the strategic RDD&D that is needed to sustain the viability of NGVs in the near- and long-term, building on the existing NGV market in California.

Also, these directives represent an emerging body of state policy and regulation seeking to aggressively reduce greenhouse gas (GHG) emissions and petroleum consumption by increasing alternative

[1] Assembly Bill 118, Section 5

transportation fuel use in California. Several proposed strategies specifically encourage lower-carbon alternative fuels, such as natural gas, for use in transportation. When compared with gasoline and diesel fuel, natural gas (as compressed natural gas (CNG) or liquefied natural gas (LNG)), is a lower carbon fuel and produces less GHG emissions in on-road and off-road/marine applications. Natural gas has also been identified as economically contributing to the AB 1007 goals for petroleum fuel displacement and "no net material increase in emissions."

The NGV industry has grown significantly over the past two decades but some technical advancements remain that, if realized, would further accelerate NGV use and displace petroleum use and provid air quality and GHG reduction benefits.

CNG and LNG have been historically less expensive than gasoline and diesel fuel on an energy-equivalent basis. However, NGVs and fueling infrastructure are more expensive. Also, natural gas heavy-duty vehicles (HDVs) have historically experienced a fuel efficiency penalty relative to diesel counterparts. Therefore, the overall economics are favorable if the net fuel cost savings (i.e., total fuel savings over diesel) can amortize the additional equipment, operation, and maintenance costs. This equation favors high fuel use applications, particularly HDVs, which represent the fastest growing NGV segment in California.

RDD&D addressing NGVs and their ability to displace petroleum-based fuels can help meet several of California's public policy priorities, particularly the goals of petroleum reduction and "no net material increase in emissions."

Guidance for the Natural Gas Vehicle Research Roadmap

The Roadmap identifies initiatives and projects that research, develop, demonstrate, and deploy advanced fuel-efficient natural gas powered transportation technologies and fuel switching strategies that are cost-effective and reduce on-road and off-road petroleum fuel use in the short and long term. This is consistent with recommendations in the *2005 Integrated Energy Policy Report*, to "...engage stakeholders to investigate how investor-owned utilities can best develop the equipment and infrastructure to fuel electric and natural gas vehicles as required by Public Utilities Code Sections 740.3, 740.8, and 451."

The *2005 Integrated Energy Policy Report* recommends that the state:

"...sponsor transportation technology and fuels research, development and demonstration to:

- Expand the availability of engines and vehicles capable of using alternative fuels, new and retrofitted.
- Reduce engine and vehicle consumption of all fuels.
- Demonstrate alternative fuel engines and vehicles and improved efficiency technologies in on- and off-road applications.
- Develop and demonstrate alternative fuel production technologies, emphasizing in-state resources."

The Roadmap presents a composite of the most needed, major NGV-related RDD&D and their sequencing. This serves the interests of all supporters of NGV RDD&D, including the California Energy Commission's Public Interest Energy Research (PIER) Program and the emerging AB 118, Federal, and private initiatives. The Roadmap was developed with the advice and input of the ARB staff, and industry stakeholders, to ensure alignment of energy and air quality objectives.

Summary of Priority RDD&D Topic Recommendations

A NGV research literature review, RDD&D gap analysis, and stakeholder views combine to suggest that the following RDD&D ideas would provide the greatest acceleration of NGV technologies in the market and help reach their full commercial potential.

Engine Development and Vehicle Integration Ideas

- Integrate available natural gas engines into more models and applications by original equipment manufacturers (OEMs), in all weight classes
- Develop a broader range of natural gas HDV engine sizes and applications
- Develop a broader range of natural gas HDVs with improved engine economics, efficiency, and emissions
- Develop NGV versions of off-road applications
- Develop a variety of hybrid natural gas HDVs
- Develop engine technology optimized for hydrogen-natural gas blended fuel
- Develop NGV homogeneous charge compression ignition (HCCI) engine technology

Fueling Infrastructure and Storage Ideas

- Develop legacy fleet engine controls and/or fueling infrastructure upgrades to accommodate fuel variability
- Research an improved composite tank safety device / installation protocol to avoid rupture in localized fire
- Develop improved handling, reliability, and durability of LNG dispensing and on-board storage
- Provide GPS guidance to NGV fueling station locations and details statewide
- Develop on-board lightweight, conformable, compact CNG storage at lower-pressure / higher-density
- Develop the next generation of home refueling for natural gas light-duty vehicles (LDVs)

Technical and Strategic Studies Ideas

- Confirm NGV economic, carbon, and emissions net benefits
- Create a clearinghouse of NGV demand and supply information
- Institute a Technology Forum for NGV stakeholders to update RDD&D needs and priorities

For these RDD&D ideas, it is the responsibility of research sponsors (e.g., PIER, future state efforts under AB 118, NGV industry, equity investors, and/or governmental agencies) to coordinate funding and activity support efforts, including a designation of which part of the effort each should undertake. It is recommended that PIER and others engage RDD&D and funding partners for collaborative projects. Further details, including rationales and suggested PIER priorities, are provided in Chapters 3 and 4.

Additional RDD&D Topics Considered

The research initiatives developed under the Roadmap are guided by topic areas that are considered to be outside of PIER's legislative scope such as research with no identifiable natural gas ratepayer benefit. The Roadmap encompasses only RDD&D of NGVs and fueling infrastructure. Fuel supply and composition issues upstream of fueling stations are related to the successful implementation of NGVs, but are discussed in the separate *Alternative Fuel Research Roadmap (AFRR)* currently being developed by PIER. Non-technical ideas that are not necessarily RDD&D, but have important roles in fostering full deployment of NGVs—such as educational programs, marketing programs, and non-technical ideas that are not necessarily within the PIER mandate—are also described.

The few areas considered out-of-scope for PIER are based on PIER legislative funding restrictions. However, these same areas may be "in-scope" for other funding sources. For example, research on natural gas sources and other alternative fuels is being addressed in the AFRR. Electricity production pathways are also addressed by other PIER programs that are supported with electricity ratepayer funds. Hydrogen production-to-use pathways are also considered out of scope for the Roadmap and the AFRR. Senate Bill 76 (SB 76) distinguishes hydrogen and the California Hydrogen Blueprint Plan from other alternative fuels, specifically, "(f)unds allocated in subdivisions (b) and (c) shall not be used for the California Hydrogen Blueprint Plan." Again, hydrogen related research is only considered to be out of scope because it is being addressed by the Hydrogen Highway Initiative led by the California Environmental Protection Agency (Cal/EPA).

The Appendix describes the summary of stakeholder ideas received during Roadmap development, including those that were not included in the RDD&D priority ideas discussed in Chapter 3 and supporting activities discussed in Chapter 4.

Overview of the PIER Natural Gas RDD&D Program

The California Public Utilities Commission (CPUC), in Decision 04-08-010, designated the Energy Commission as Administrator of statewide natural gas-related public interest activities of the PIER Program. Senate Bill 76 (Committee on Budget and Fiscal Review. Energy. Chapter 91, Statutes of 2005) allows up to one-third of the natural gas PIER funds in any program year to be used for transportation-related public interest energy RDD&D. This research must provide natural gas ratepayer benefits, such as reduced impact from global climate change, reduced health risks related to poor air quality, reduced volatility of transportation fuel prices, and reduced economic impact from dependence on petroleum. SB 1250 (Perata, Chapter 512, Statutes of 2006) further modified the PIER program by setting transportation-related RDD&D as a state priority. PIER began managing the natural gas public interest program in 2005, starting with an annual budget of $12 million, and increasing each year by $3 million, and capped at $24 million. For 2007, the PIER natural gas research budget is $18 million.

For 2007, one-third of the program's funds, $6 million, was allocated to transportation-related RDD&D. A share of that amount will be allocated to NGV RDD&D, with exact amounts to be determined annually based on relative value of the competing research topics across all alternative fuels and vehicle types.

The *PIER Natural Gas Research Investment Plan 2007-2011* lists five key issues, one of which being a "clean and diverse transportation system." Strategic objectives related to this key issue are also identified. They are:

1) "Identify advanced transportation research opportunities that optimize the goals of reducing petroleum dependence, enhancing energy and economic security, and expanding environmental and public health benefits."
2) "Develop and demonstrate technologies to improve efficiency within the transportation system."
3) "Develop and demonstrate alternative fuels, vehicles, and fueling infrastructure."
4) "Develop the knowledge base and advanced analytical tools for future decision-making and informed transportation policy."

Several "Transportation Research Solutions" are detailed in the Research Investment Plan and address this key issue and the strategic objectives. The Roadmap provides a vision and guidance for implementing those solutions for alternative fuel dispensing and transportation technologies. The remaining Transportation Research Solutions not addressed by the Roadmap focus on the broader context of alternative fuels, especially renewable alternative fuels such as ethanol and biodiesel; those topics are addressed in a separate alternative fuel research roadmap effort.

In general, a research roadmap is prepared at the topic level and involves a broad literature review, identification of institutions conducting relevant research, and evaluation of the relevancy of other ongoing research. The Roadmap efforts:

1) define the "state of the art" and gaps in existing and planned NGV RDD&D;
2) determine the degree to which other research initiatives are addressing the perceived need in California;
3) identify other possible co-sponsors capable of leveraging relatively scarce research funding.

Based on this analysis, the resulting roadmap defines recommended short,- mid- and long-term goals/objectives, required level of funding, timeframes, and specific research activities. This effort is a research "gap" analysis that limits duplication, facilitates active collaborations with other research institutions, utilities and government agencies, and allows for balancing timeframes, risk, and maximizing public benefit.

In summary, the research roadmap will ensure that public purpose NGV RDD&D activities are directed towards developing science or technology, are not adequately addressed by competitive or regulated entities, and benefit California citizens.

Inclusion of the comments below do not indicate a preference or implication on the part of the PIER program that such projects will or should be awarded PIER funding.

CHAPTER 2: NGV Potential Value

This discussion serves to illustrate the potential value of California's RDD&D investment in NGV advancement. It indicates that NGVs could play a significant role in California's drive to advance its environmental and energy resource management goals for transportation. The value of NGV technology is not in any anticipated dominance in meeting those goals, but rather in its potential to make a significant contribution, along with a variety of other technologies, in a portfolio of cleaner-fuel alternatives. Eventually the transportation sector may rely primarily on radical changes in motive power such as fuel cells, advanced batteries, and cellulosic biofuels, but developmental risks and uncertainties are likely to delay widespread use of such options for decades. NGV technology appears to be among the most appropriate interim solutions for use during that crucial transitional period to reduce petroleum dependence and its environmental effects.

To what degree might NGV technology be developed to help meet California's transportation policy goals? Is this a reasonable strategic RDD&D investment for California? NGV technology, based on the AB 1007 analysis performed in 2007, shows a high potential for greenhouse gas reductions on a well-to-wheels basis (11-23% HDVs, 20-30% LDVs) as well as substantial potential to offset petroleum consumption (up to 99%)[2]. Even higher potential may exist, depending in large part on the removal of current obstacles through RDD&D choices and successes. Collaborative research efforts with other funding agencies and private technology developers may produce key strategic breakthroughs in a broad range of NGV technology choices and needed fueling infrastructure. Pursuing strategic public interest research investment that accelerates NGV production, infrastructure, and usage in turn expands the viability of an existing alternative fuel contributor to California's transportation policy goals.

As all types of NGV choices, overall fuel economy, and refueling convenience increase, NGVs can become a much more competitive and attractive choice for many vehicle users. The 2007 AB 1007 analysis by Energy Commission staff evaluated several hypothetical scenarios for possible petroleum and GHG reduction and cost associated with all alternative fuels. Table 2-1 illustrates the Energy Commission staff's hypothetical scenario for future NGV fuel use. It is important to note that this scenario–along with other scenarios developed as part of their analysis–was not intended as a prediction but rather as a tool to assess an alternative fuel's ability and timing to help achieve petroleum and GHG reductions, among other attributes.

[2] California Energy Commission, "Full Fuel Cycle Assessment: Well-to-wheels Energy Inputs, Emissions, and Water Impacts", August 1, 2007. CEC-600-2007-004-REV

Table 1. Maximum Feasible Natural Gas Use as a Transportation Fuel in California

Year	2012		2017		2022	
	Fuel Use (MMgge)	GHG avoided (MMT/year)	Fuel Use (MMgge)	GHG avoided (MMT/year)	Fuel Use (MMgge)	GHG avoided (MMT/year)
Maximum Feasible Scenario	**306**	**1.5**	**518**	**2.5**	**885**	**4.4**

Source: California Energy Commission, "State Alternative Fuels Plan, Proposed Commission Report" November 2007, pg. 47. CEC-600-2007-011-CMD

Assuming natural gas prices continue to diverge from rapidly increasing petroleum prices, NGVs have the potential to reach and exceed the "Maximum Feasible Scenario" market penetration levels given in Table 1. In fact, the Energy Commission states that, "natural gas use in heavy-duty vehicles alone could represent about 36 percent of the freight and off-road vehicle fuel use by 2050."[3] Thus, on- and off-road NGV market penetration could surpass these levels and play an even greater role in reducing California's petroleum dependence and reducing GHGs, particulate matter (PM) , oxides of nitrogen (NO_x), and air toxics (e.g., formaldehyde). This vision illustrates the value of a NGV RDD&D program within a larger portfolio of other alternative fuels and vehicles, with PIER and other public and private stakeholders working closely to make the strategic breakthroughs that are needed to make it a reality.

Technical Potential for NGVs

On-Road Medium-duty and Heavy-Duty Vehicles: In the next 5-10 years, we can expect that medium-duty vehicles (MDVs) and HDVs4—primarily HDV refuse trucks and buses, with some port drayage trucks and other goods movement vehicles—will continue to be the dominant classes for NGV applications. Line-haul trucks (typically the largest and heaviest class of HDVs) are considered to be a longer-term NGV application while return-to-base truck and bus operations are more practical near-term applications due to their use of centralized refueling infrastructure. NGV emission advantages should continue (as discussed below), and performance, efficiency, and range of engine sizes should also increase with effective RDD&D initiatives. Sales volumes should grow as focused and collaboratively-funded RDD&D solves basic cost challenges and permits a more attractive manufacturer business case. Though outside the scope of the Roadmap, governmental incentives and mandates may also emerge in

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[3] California Energy Commission, *Proposed State Alternative Fuels Plan.* October 19, 2007. Pages ES-5 to ES-7. CEC-600-2007-011-CTF.

[4] Throughout this document, "heavy-duty vehicle" is defined as greater than 14,000lbs gross vehicle weight rating (GVWR). "Medium-duty vehicle" is defined as a commercial vehicle between 8,500 and 14,000lbs GVWR, and includes applications such as shuttle buses, street sweepers, utility trucks, and pick-up and delivery trucks. This usage is consistent with the vehicle weight class definitions for the California on-road vehicle emission standards.

the near future to further encourage more engine manufacturers, vehicle integrators, and fueling and storage providers to successfully enter the NGV market.

Non-Road Heavy-Duty Vehicles: In addition to potential on-road diesel truck and bus replacement, the heavy-duty NGV market also has the potential to expand further into non-road vehicle markets. Heavy-duty off-road, rail, and maritime diesel uses today account for a substantial share of total fuel consumption and emissions. These non-road market sectors have not yet been required to meet on-road near-zero emission regulations, leading to opportunities for significant emission benefits remain large. These markets represent a significant broadening of applications for the improved heavy-duty natural gas engines anticipated through current and proposed research and development. Initial applications could occur within this decade and expand substantially over the next. Target markets may include railway locomotives and utility vessels such as tugs, tows, ferries, tour boats, and small coastal freighters. Off-road construction and mining vehicles--from haulers to excavators--can also benefit from these improvements and further expand the market, particularly as emission regulations broaden to include them.

Light-Duty Vehicles: Light-duty[5] NGVs as well as gasoline-to-natural gas conversions are already produced and sold in large volumes in Asia, South America, and Europe. The LDV market in this country is also promising over the longer term. Current and projected gasoline use in LDVs dominates the vehicle world, and projected diesel LDV use will only marginally moderate overall petroleum consumption and emissions. In contrast, today the natural gas fueled Honda Civic GX sedan is among the cleanest and most fuel-efficient small cars available in the US. The Civic GX is being marketed to private customers, focusing on urban high-occupancy vehicle lane access and home refueling opportunities, as well as to fleets motivated by Energy Policy Act compliance. In addition, light-duty NGVs will also play a key role in acquainting the now-unfamiliar public with the gaseous fueling that is likely to be required for initial hydrogen fuel cell vehicles. Strategically focused collaborative RDD&D to achieve economies of scale and permit a broader array of LDV choices can gradually increase market appeal as well as engagement by vehicle manufacturers and infrastructure providers—particularly for public fueling facilities as well as economical in-home fueling systems.

Hybrid NGVs and Fuel Cell Vehicles: As hybrid vehicles become more widely accepted, integration of natural gas into advanced hybrid development programs and products all NGV markets may occur. The gradual emergence and acceptance of fuel-cell vehicles will be accelerated by NGVs because of the public's growing familiarity with pressurized natural gas fueling as a bridging technology for hydrogen use.

Infrastructure: NGV fueling infrastructure includes onsite compression (or insulated storage, in the case of LNG), storage facilities, containments, and vending equipment including status monitoring, measurement, controls, and connections. The cost of LNG, CNG, and liquefied to compressed natural gas (LCNG) infrastructure can be gradually reduced over the next decade, notably through manufacturing refinements and increasing scale-economies. In the coming decade, possible breakthroughs in practical adsorbent natural gas storage systems may occur, including storage on vehicles. This technology may or may not prove to be dominant over compression for NGVs in later years.

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[5] Throughout this document, "light-duty vehicle" is defined as less than 8,500lbs GVWR. This is consistent with the LEV II weight class definitions for the California on-road vehicle emission standards.

The durability and reliability of CNG and LNG infrastructure can also be improved significantly within the decade, primarily through research and development of improved materials and manufacturing processes.

CHAPTER 3: Priority NGV RDD&D Gaps and Potential Solutions

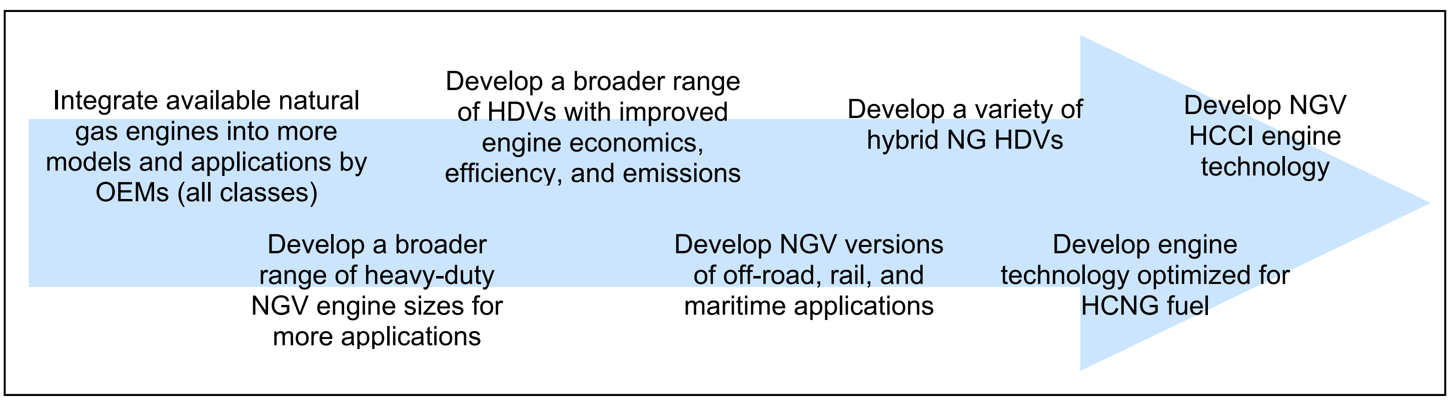
An initial activity of Roadmap development was a review of relevant literature and stakeholder experience in the field of NGV RDD&D, in order to avoid duplication of prior efforts. This review identified the RDD&D programs that already have been implemented as well as unmet NGV research needs resulting from RDD&D gaps and thus have not reached full deployment. These RDD&D gaps act as barriers to NGV market viability, whether for particular NGV applications or the NGV market as a whole.

To ensure the most strategically important of these RDD&D gaps were addressed, additional stakeholder input was solicited at a Roadmap Workshop held at Asilomar Conference Grounds in August 2007. At the Workshop, participants were asked to identify the priority gaps that should be addressed by this Roadmap. This chapter describes these priority gaps and the potential program ideas for addressing them. A complete list of RDD&D gaps identified during the development of this Roadmap can be found in the Appendix.

Engine Development and Vehicle Integration

The priority RDD&D gaps for engine development and vehicle integration range from a lack of heavy-duty and off-road engine sizes/capacity to how natural gas engines will satisfy future greenhouse gas and pollutant emission regulations. A summary and relative sequencing of the potential solutions for these priority RDD&D gaps are given in Figure 1, followed by detailed descriptions below.

Figure 1: Relative Sequence of Priority RDD&D Ideas for Engine Development and Vehicle Integration



The relative sequencing presented in Figure 1 was determined using stakeholder input regarding RDD&D priorities, and by considering which of these are needed the most in the near term and which are more viable in the near-term. For example, although expanded integration efforts and development of larger engines are both needed in the near-term, expanded integration options could be deployed more quickly. Improved engines and off-road applications will require more time to reach the deployment phase than expanded integration and size options, but would still bring significant benefits to the NGV marketplace. The final three ideas listed are further away from full market deployment and, in the case of the hybrids and HCCI development, may benefit from waiting for development (including trouble-shooting) on conventionally-fueled engines, rather than developing the NG versions from scratch. Ultimately, these final three technologies will also provide efficiency and emissions benefits for NGVs, but would be better utilized by the expanded market of NGV options created by the first four options.

Although each of the ideas shown in Figure 1 addresses a development/integration gap, in order to offer these as viable options in the marketplace, there must also be demonstrations and deployment activities as well. Visible demonstrations of existing and newly developed NGVs—including substantial technical and economic analysis and fleet-targeted publicity of the results —provide potential suppliers, customers, and investors with the information they need to embrace new products like NGVs. Deployment support activities build on demonstrations by using publications, web information, conference presentations, and trade show exhibits to get products into use by the market leaders and innovators. Deployment support also includes providing technical success information to legislators and regulators in support of NGV industry efforts, to aid the development of new legislation and regulatory policies. All together, these activities serve to maintain the viability of all NGVs in the marketplace. Overall, highly visible technology demonstration and deployment showcases the real value of research investments and increases public confidence for all parties involved in the market, leading to more viable NGV options overall.

Integrate Natural Gas Engines into More Models and Applications by OEMs (All Classes)

Vehicle integration is a significant hurdle to greater NGV availability and market penetration. Original equipment manufacturers (OEMs) are generally unwilling to allocate engineering resources to design the integration of natural gas engines into new chassis without assurance of product sales. The high cost of developing and certifying a new NGV model is also a significant hurdle to broadening NGV options for on-road and off-road applications. This gap could be resolved by offering cost-sharing incentives to OEMs for natural gas engine integration, leading to more chassis options for existing engines. Developing a business case to prove to OEMs that it's worth doing would bolster this effort. Also, fostering the development of a needs clearinghouse for NGV fleet managers and a NGV technology forum for all NGV stakeholders (as described below in Chapter 3.3) would provide OEMs with a more accurate representation of market demand, allowing them to better assess the potential demand for a given integrated product.

> RDD&D Gap: Need to integrate, demonstrate, and deploy additional natural gas vehicle models of all classes, as OEM vehicles. This includes HDV applications such as goods-movement (e.g., port drayage) trucks; MDV applications such as shuttle buses, street sweepers, utility trucks, and pick-up and delivery trucks; larger passenger vehicle (LDV) applications, such as SUVs.

Integration Issues Specific to Medium- and Heavy-Duty Vehicles

Natural gas engine development is the first of many steps in getting a new MDV or HDV on the road. Engine manufacturers develop the engines while truck original equipment manufacturers (OEMs) or third-party integrators are responsible for integrating the engines and fuel-storage systems into the chassis.

The issues involved are complex. Because costs of designing the vehicle integration are significant, product offerings from truck manufacturers are limited. Even a manufacturer who produces a natural gas product probably often offers only one vehicle model with a single natural gas engine as an option. By comparison, diesel MDV and HDV manufacturers are able to offer many different products with several different engine options (and power ratings) per platform. Market growth will involve engine and chassis manufacturers expanding their natural gas vehicle product lines and engine options.

To date, truck manufacturers typically install a given manufacturer's natural gas engine into their chassis as they do the conventional engine from the same manufacturer. Given the reduced power density of natural gas engines and their lower efficiency, trying to integrate the engine into the chassis without redesigning the entire drivetrain to match the performance of the natural gas engine can lead to less-than-desirable results — results that customers are not likely to accept conventional performance. Conversely, proper design and integration of appropriate engines into chassis can lead to excellent performance, as demonstrated by Department of Energy (DOE) efforts in the ultra-clean, ultra-safe natural gas school bus development project.[6] Also, for some medium-duty applications, it may be more cost-effective overall to base the natural gas engine on a gasoline engine, as opposed to diesel.

While design and cost of new fuel systems are important issues, the safe and efficient integration of those systems into vehicles involves several technical hurdles. Greater fuel storage can be accommodated on-board using better design integration with the chassis, especially because most CNG vehicle applications require multiple fuel containers for adequate fuel capacity. Solenoid valves, regulators, check valves, pressure-relief devices, and pressure-relief venting need to be designed as a system for the ultimate safety of the user. Durability, reliability, and crash-worthiness of fuel systems and safety components are essential for system integrity and operational success.

In some cases, redesign of the chassis is needed. This is a case where scale-economies can be critical. In order to properly address this integration RDD&D gap, MDV and HDV OEMs may need incentives and/or cost-sharing to engineer and certify fully integrated natural gas packages into more chassis.

Integration Issues Specific to Light-duty Vehicles

Some of these issues also apply to LDVs. In the light-duty case, vehicle OEMs are total system developers from engine-to-chassis integration. But the one-size-fits-all approach does not work for NGVs any better than it does for gasoline vehicles. While NGVs are being sold, customers are still looking for additional vehicle type, engine, transmission, differential, and fuel storage options than those that are currently available.

Even though domestic and import manufacturers continue to produce light-duty NGVs for foreign markets, Honda is currently the only OEM to provide light-duty NGVs to the U.S. market. Honda is targeting the private commuter with HOV lane access and home refueling options that provide convenience in addition to fuel price savings, to expand the market beyond fleets motivated by EPAct requirements and fuel price savings.

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[6] *Development of an Ultra-safe, Ultra-low Emissions Natural Gas-fueled School Bus: Final Report.* NREL/SR-540-23842 (March 1998) available at: http://www.eere.energy.gov/afdc/progs/view_citation.php?3755/SBUS (as of December 11, 2007)

Given that light-duty NGVs are being produced in large volumes for the global non-U.S. market, one option—in addition to incenting integration of engines into additional models—is to review viable means for bringing foreign models/designs to the US. Foreign versions of NGVs are experiencing large growth, with recent announcements from India, Pakistan, and other countries around the world regarding additions of thousands of NGVs to their taxi fleet and mass transit systems. These increases are a mix of conversions and OEM vehicles. Even companies with a strong U.S. presence have not marketed their light-duty foreign NGV models in the U.S.

In addition to uncertainty of market demand, different safety and emissions certification standards, along with different incentives and mandates, serve as barriers to selling foreign light-duty NGV models in the U.S. For example, California vehicles must be certified for use by EPA and by ARB—the latter requires challenging process that must be undertaken for each engine/vehicle model combination.

There are also multiple retrofitters/upfitters offering gasoline-to-natural gas conversions (either to gasoline/natural gas bi-fuel or dedicated CNG systems) for specific domestic vehicle models. However, conversion companies' vehicle integration activities are constrained, because ARB certification rules require that NGV conversions be certified for specific vehicle models and model years, like their OEM counterparts. This policy requires that conversion companies must shoulder the cost for certifying their product for a variety of models before broadening their product offering. There are good reasons for this policy, but it substantially adds cost and reduces the incentive for entering and broadening the NGV conversion market.

In order to properly address this integration RDD&D gap, LDV OEMs and converters may need some testing and certification assistance in collaboration with ARB. Given that ARB is motivated to seek the greatest emission reductions possible, there may also be greater opportunity for collaboration in sectors with less-stringent regulations (such as off-road equipment), where natural gas conversions would produce a greater emissions benefit on a per vehicle basis.

Develop a Broader Range of Heavy-duty NGV Engine Sizes for More Applications

There are relatively few engine models and power options today in the natural gas engine market. More engines options are needed, especially for heavy-duty applications requiring 400-600hp and 12-16L displacement. Trucking companies in particular are interested in the 400-600hp options. Larger engine sizes will also be needed to exploit the opportunities in marine, rail, and off-road applications. If marine-based natural gas engines are developed in the future, they will need to be "marinized", a process that engine manufacturers are accustomed to doing for diesel.

> RDD&D Gap: Develop, demonstrate, and deploy larger horsepower/displacement (e.g., 400-600 HP range, 12-16L displacement) natural gas engine offering(s) suitable for heavy-hauling and/or off-road applications such as waste transport, coal hauling, and semi-tractor trailer applications; this would allow NGVs to serve more high-fuel-consuming transportation markets.

This gap could be resolved by offering cost-sharing incentives to OEMs to support the development of engine cost reductions and additional engine sizes to gradually feed into the OEM path and strengthen that vehicle supply pool. Also, an offer of testing and certification assistance for any new engines, in collaboration with ARB, may be warranted.

Improve HDV Engine Economics, Efficiency, and Emissions

> <u>RDD&D Gap</u>: Develop a broader range of heavy-duty NGVs with improved cost-effectiveness, engine thermal efficiency, and emissions.

Historically, natural gas HDVs—with spark-ignited (SI), throttled natural gas engines competing with compression-ignited, unthrottled diesel engines—have an overall fuel economy penalty relative to conventional vehicles (especially at idle and low loads), which is a significant barrier to serving as a broadly viable alternative transportation fuel. Some heavy-duty engines have made advances—Westport HPDI engines provide diesel efficiency and CAT/CAP dual fuel engines provide intermediate efficiency—but not yet for all horsepower and displacement ranges.

RDD&D is needed to improve the operating efficiency and power density of heavy-duty natural gas engines. Despite the presently favorable price difference between diesel and natural gas, the lower fuel efficiency of heavy-duty SI natural gas engines erodes fuel cost savings and remains a hurdle to broader adoption. The industry is striving to increase natural gas engine fuel efficiency to within one percent of diesel and beyond. These performance improvements must be achieved while meeting emission standards. For example, new transit bus and refuse truck SI natural gas engines have gone from lean-burn to stoichiometric designs in order to achieve both emission and fuel efficiency improvements over recent lean-burn engines, utilizing exhaust recirculation, oxygen sensing, and three-way catalysts common to light-duty NGV and gasoline vehicles.

Many of today's SI natural gas engine offerings come close to matching diesel engine fuel efficiencies at full-load but are less efficient at part-load. In urban applications, where vehicles operate for long periods of time at idle or low-load conditions, throttling losses are significant and adversely affect fuel efficiency and, hence, life-cycle economics.

There are several possible technologies that could address this engine efficiency problem, including cylinder deactivation, variable-geometry turbocharging, advanced controls, multi-port fuel injection, hybridization, and even high-pressure direct injection (HPDI). Improving energy efficiency improves fuel economy. Because fuel cost savings are used to justify offset incremental vehicle and infrastructure costs, improving engine efficiencies will enhance the market competitiveness of NGVs.

Another area in which natural gas engines need to be improved is power density. Current SI natural gas engines have power ratings 10-20% lower than their diesel counterparts. This lower power density is due to the lower compression ratios and knock sensitivity of SI engines. Power enhancements -- including combustion chamber geometry optimization, air motion, heat transfer characteristics, and materials with greater thermal capacity -- represent some of the technology developments that would allow for diesel-like power density from natural gas engines. For example, the HPDI engine technology being developed by Westport is an alternative natural gas technology that provides diesel-like performance and avoids typical SI performance limitations including poor idle fuel efficiency. Research and development of HCCI or HCCI-type technologies for both gasoline and diesel engines may also provide opportunities for natural gas engine improvement.

Development of cost-effective closed-loop control systems is critical to maximizing performance and minimizing emissions of NGVs. Keys to this technology are cost-effective sensors with sufficient performance (e.g., range, repeatability, accuracy, life, contaminant tolerance) to detect engine knock, engine misfire, engine torque, exhaust gas oxygen content, and fuel composition. Engine manufacturers are increasingly using feed-forward or "model-based" engine controls including "virtual sensors" that go beyond earlier closed-loop or "feed-back" approaches. HCCI concepts require control of combustion events on a cycle-by-cycle basis that may change too quickly to wait for feed-back information and virtual sensing can avoid trying to devise sensors for difficult or impossible locations. Development and testing of these concepts should be included as part of the engine development RDD&D program, followed by demonstration and deployment support.

Again, the challenge will be to improve part-load efficiencies, while simultaneously maintaining lower emission levels and reducing costs. Development efforts in the technologies described above, along with demonstration and deployment support, with make NGVs a more viable alternative fuel transportation option.

Exhaust Emission Reductions

As NGVs are designed to emit less NOx, methane, ethane, and propane emissions tend to go up. There is a need to address this through injector technology, combustion technology, and exhaust emissions control technology. There is also a need to develop and demonstrate catalyst formulation than can oxidize methane, ethane, and propane, as opposed to diesel catalysts formulated to oxidize heavier hydrocarbons (i.e., those with ~10-15 carbon atoms).

> RDD&D Gap (not specifically identified as a "priority" gap, but related to one): methane emissions from NGVs are currently unregulated, but as GHG emission standards are rolled in, methane will be very important to control.

Future emissions concerns, such as the toxicity of natural gas exhaust emissions, may become an issue as lower particulate matter (PM) standards tend to drive up formaldehyde emissions (in diesel vehicles). There is a need to determine how well future NGVs will control toxics (e.g., formaldehyde) emissions better than diesel. Also, ultra-fine PM ($PM_{0.1}$, that is, particulate matter less than 0.1 microns in diameter) may be found to be more harmful than larger PM—in which case, it is unclear if NGVs be able to control $PM_{0.1}$ better than diesel vehicles. Answering this concern of PM0.1 control includes determining where $PM_{0.1}$ originates in NGVs (e.g., in the lube oil, fuel, or the combustion chamber).

Light-duty NGVs were the first to achieve ULEV and SULEV emission certification in LDVs. Natural gas also has led the way to low emissions from heavy-duty engines. Much of the progress natural gas has made in penetrating specific markets (e.g., transit) is attributed to the ability of natural gas engines to offer these superior emission reductions. For example, the MY2007 Cummins-Westport ISL G engine has been certified to meet the EPA MY2010 emission standards. However, by MY2010, Federal and California emission standards will hold on-road heavy-duty NGVs to the same emissions standards as their conventional counterparts. In light of this, further NGV engine RDD&D efforts will be needed to assure a strong future market for NGVs in the light-, medium-, and heavy-duty markets.

To date, natural gas engines achieve lower emissions primarily due to fundamental fuel properties, in-cylinder combustion modifications, and the use of simple oxidation catalysts. There is a new generation of post-combustion aftertreatment technology that can be employed on natural gas engines to further reduce emissions of NOx, PM and air toxics. Future RDD&D should include testing and evaluation of these technologies and applications, then demonstrating and deploying them.

Develop and Certify Off-Road Vehicles, Rail, and Maritime Applications

The San Pedro Bay Ports Clean Air Action Plan calls for replacement of 5,300 Class 8 diesel trucks hauling goods into and out of the Ports of Los Angeles and Long Beach with LNG-powered trucks over the

> RDD&D Gap: Port/off-road vehicle types, such as yard tractors and crane transports, need to be designed to accept natural gas engines (e.g., higher heat rejection loads need to be accommodated and existing equipment designs need to be modified in order to integrate these engines.). LNG-fueled yard hostlers are currently under demonstration at the Port of Long Beach; no port vehicles are in the deployment phase

next 4 years, using various funding sources including the Bond Initiative passed in November 2006. Incentives such as this are needed to encourage development of off-road NGVs. Starting with vehicle applications that are similar in function to current on-road NGVs, manufacturers could develop applications for off-road port equipment such as yard hostlers, achieving significant emissions reductions compared to existing diesel equipment.

In light of a recent ARB decision to regulate construction fleet emissions and fleet emissions from other off-road equipment, the off-road sector represents a largely untapped market for NGVs. Market growth in this sector would require future research and development efforts in expanding product offerings over applications and horsepower ranges. Historically, Toyota has offered one or two natural gas industrial truck (forklift) models, as has Yale and Clark. In the conversion market, Questar in Utah and KeySpan in New York have historically offered natural gas forklift retrofits.

Similar integrations issues arise when considering marine applications, especially because boat-building firms in the U.S. have even less experience with natural gas than do truck manufacturers. Except for the basic hull form, most vessels are generally custom-designed, allowing for the additional engineering required for the natural gas system to occur during the time of boat design and construction. In addition, most passenger ferries in the U.S. are built with significant federal support from the Department of Transportation (DOT). Important considerations to be included in a marine RDD&D plan are: 1) development of safety standards and operating procedures; and, 2) working with the Coast Guard to gain endorsement. California has begun to set limits on emissions from port marine vessels, opening an opportunity for NGV versions of such vessels—however, this, too would require incentives to develop and demonstrate for future deployment.

Like marine applications, rail transportation has significant potential for emissions reductions, but would require additional engineering to integrate a natural gas engine into a locomotive. Although interstate locomotives are under Federal jurisdiction for emissions, those engines that stay within California (such as switchers, which operate with the rail yard) can and will continue to be targeted for emission reductions by the ARB and local air districts.

Develop, Demonstrate, and Deploy Hybrid Natural Gas Heavy-duty Vehicles

Hybrid-electric NGVs offer significant promise for clean transportation using a domestic fuel. Because of their inherently increased fuel economy, hybrids require less total fuel storage to achieve acceptable driving range per fill-up. This helps resolve two of the market barriers to NGVs – namely, reduced range and loss of load space. Also, using battery power to minimize idle and low-load engine operation can materially contribute to the cost-effectiveness of heavy-duty NGVs in stop-and-go urban service. Substantial RDD&D is required to address integration and cost issues.

> RDD&D Gap: managing the power density, developing the system, and lowering technology cost of hybrid NGVs. There may be synergy with hybrids developed for conventional fuel applications, but ultimately, the controls will need to be tailored to the load profile/power management needs of the NGV and its application.

The hybrid-truck concept has been researched and demonstrated since the late 1990's for conventional transit and trucks, as well as military applications. Diesel vehicle users are starting to want hybrid versions of class 8 vehicles as well. Currently, there are several hybrid-truck demonstrations in progress, including conventional hybrid HDVs, a few NGV-hybrids, and a hybrid hydrogen transit project by ISE for SunLine transit. All of this activity may help enable a comparable technology for NGV trucks.

Hybridization of a variety of CNG/LNG vehicles still requires a development, demonstration, and deployment program. Such a program would investigate the proper type of hybridization for a given application along with the power management and power output. For example, hydraulic systems may offer a synergy with refuse haulers—which already use a lot of hydraulic for operation— while ultracapacitors, batteries, or flywheels may be better suited for other applications.

Develop Engine Technology Optimized for Hydrogen-CNG Blends

Demonstrations of hydrogen-CNG blends (HCNG-blends)[7] have involved re-calibration of engine controls and modification of engines themselves. There are examples of HCNG-blend NGVs in the demonstration phase for transit applications and a few trucks. For example, Sunline Transit has been operating some demonstration HCNG-blend buses since 2001.

RDD&D Gap: Develop hydrogen-natural gas blend options that increase vehicle fuel efficiency and reduce emissions from legacy fleet. This may incorporate an engine retrofit and/or engine control reprogramming.

Combining hydrogen with natural gas further reduces the amounts of NOx produced and facilitates ignition of highly-lean and highly-exhaust diluted fuel mixtures. Demonstrations for specific transit-size engines show that a 50% NOx reduction is possible when using HCNG-blends. However, engine controls and natural gas engines generally will have to be modified to accommodate larger concentrations of hydrogen in CNG. If it could be shown that reprogramming existing engine controls (without an engine modification) were possible to accommodate HCNG-blends, then it may be possible to use HCNG-blends in existing 1.5 to 2.0 g/bhp-hr NOx engines even further, adding up to significant benefits.

This technology needs additional research to show at what concentrations (if any) engine modifications would not be needed to accommodate HCNG–blends. Also, research is missing on the long-term deterioration effects of hydrogen in the combustion chamber, even in low concentrations. Also, economic incentives will be needed to support this development, perhaps in concert with efforts to develop hydrogen infrastructure and use.

Develop NGV HCCI Engine Technology

The major technical challenge in Homogeneous charge compression ignition (HCCI) is the control of combustion, with most of today's engine prototypes being able to sustain the HCCI combustion mode only at low to medium engine loads. It also can produce increased HC and CO emissions.

HDV HCCI is not expected to be available in the near-term, given the low to medium engine load requirements. However, GM is demonstrating LDV HCCI-powered concept vehicles—a production-based Saturn Aura and the Opel Vectra, both with a modified 2.2 L Ecotec 4-cylinder engine—that drive like conventionally-powered vehicles at lower speeds, and switch to standard gasoline operation a highway speeds.

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[7] Hydrogen-CNG blends are referred to collectively as HCNG-blends throughout this report. However, currently, there are two varieties of HCNG-blends being demonstrated in vehicles: "Hythane©" and "HCNG". The current definitions of these are: "Hythane©" is ≤20% hydrogen in natural gas and "HCNG" is > 20% in natural gas. NOTE: Because this is a developing fuel option, discussions of this topic outside of this document tend to overlook this distinction and generalize all HCNG-blends as either Hythane© or HCNG.

Fueling Infrustructure and Fuel Storage Development

The gasoline and diesel engine manufacturers are developing HCCI already, but the technology is development and demonstration phase. Given the complexity of the system, requiring advanced computer controls, this is viewed as an opportunity for tech transfer into the NGV product after the diesel/gasoline counterpart has been developed, rather than try to do the research on a much more limited research budget. However, there are some complimentary compression ignition technologies that could be supported in anticipation of HCCI incorporation into NGVs.

> RDD&D Gap: Homogeneous charge compression ignition (HCCI) is a low temperature combustion technology utilizing compression ignition of well-mixed air fuel mixture. Compared with a conventional diesel engine, HCCI emits ultra

Compression Ignition Engines

Compression ignition natural gas engines could hold great advantages over SI engines in terms of fuel efficiency and performance. Because they would use diesel-like engine systems, they also could allow engine manufacturers to produce only one engine platform type (versus today's two). This could improve the economies of scale in manufacturing, reduce the cost of natural gas engines and promote greater resale compatibility in the marketplace.

Continued development of part-load fuel control strategies, combustion process optimization, and CNG/LNG injector systems—such as HPDI and diesel "micropilot" injectors—are relevant needs under a compression ignition engine RDD&D program. Ultimately, this will facilitate transfer of HCCI from gasoline/diesel engines, once the technology has matured.

The cost of installing fueling infrastructure for CNG and LNG vehicles is high, representing about one-third of the total cost of conversion to natural gas. The vehicle cost differential accounts for the other two-thirds of the cost. CNG fueling infrastructure costs are dominated by the cost of compressors, on-site fuel storage, dispensers, dryers and controls. LNG fueling infrastructure costs are dominated by fuel storage, jacketed piping, transfer pumps, safety equipment, and dispensers.

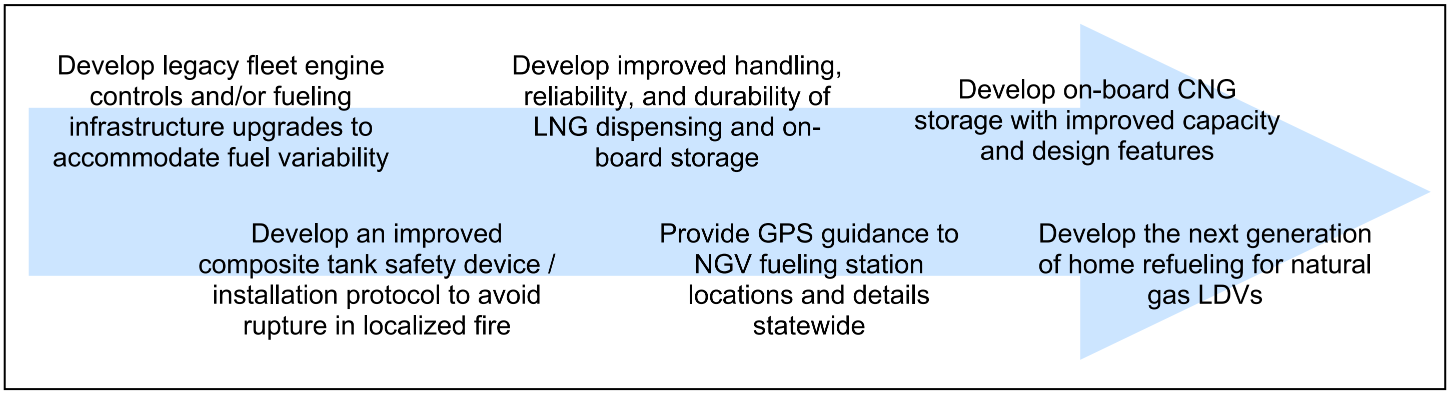
Liquefied-compressed natural gas (LCNG) fueling infrastructure—serving both LNG and CNG vehicles at the same location—requires similarly high capital costs. LCNG fueling infrastructure costs are dominated by LNG storage and pumping elements, vaporizers to convert LNG to CNG, and CNG dispensing elements. Unlike a CNG-only station, however, LCNG dispensing infrastructure vaporizes LNG instead of compressing low-pressure pipeline gas, and thereby typically enjoys lower operational costs for the same CNG output.

Because of these high cost elements, the growth of infrastructure expansion is economically tied to expansion of high fuel use fleet applications. Further RDD&D to reduce the cost of infrastructure hardware and improve the durability and reliability of fueling systems is necessary to facilitate progress towards public benefit goals. In turn, lower costs and better reliability and performance will permit faster market expansion. In many cases, customer concerns over available infrastructure need to be addressed before they can contemplate purchasing more NGVs.

The priority RDD&D gaps for fueling infrastructure and fuel storage development range from developing conformable storage tanks to implementing a means for legacy fleet vehicles and other NGVs to handle fuel variability. A summary and relative sequencing of the potential solutions for these priority RDD&D gaps are given in Figure 3.2. Detailed descriptions are provided below.

The relative sequencing presented in Figure 2 was determined using stakeholder input regarding RDD&D priorities, and by considering which of these are needed the most in the near term and which are more viable in the near-term. For example, legacy fleets are susceptible to fuel variability problems and will need a near-term solution to continue operating in areas where high-BTU gas is supplied. Composite tank safety and LNG fueling ideas were identified as near-to-mid-term needs because they are important, but not immediately critical to the NGV marketplace. The last two ideas are also important, but will require more development, demonstration, and deployment time than the others, and thus are considered more long-term.

Figure 2: Relative Sequence of Priority RDD&D Ideas for Fueling Infrastructure and Storage



Develop Legacy Fleet/Fueling Infrastructure Upgrades to Accommodate Fuel Variability

This concept seeks a potential retrofit or fuel modification technology that allows legacy engines to handle higher-BTU "hot gas" composition changes. This may be a matter of changing the engine control module in combination with additional sensors to better respond to fuel composition variation.

Among the legacy fleet—the early heavy-duty NGVs from the last decade, totaling about 1,000 vehicles—vehicles with open-loop controls can't handle extreme variations in gas quality at the high-BTU end, because in extreme cases, the hot gas can quickly burn up engine pistons and rings. On the lean burn engines, you'll have enough air to burn high-BTU gas, but end up with knocking/detonation. At the opposite extreme (with a low-BTU gas), you would experience power degradation—undesirable, but not damaging like the hot gas case.

> RDD&D Gap: Need a means for compensating for variations in gas quality. Determine natural gas fuel composition requirements for heavy-duty engines, characterize fuel composition tradeoffs affecting the three generations (older open-loop lean-burn (the "legacy" fleet), newer closed-loop lean-burn, and new stoichiometric three-way catalyst engines) of heavy-duty natural gas engines, and then recommend a natural gas quality specification that provides the optimum benefit balance for California.

Southern California Gas (SCG) has been limiting new station growth based on whether or not local pipeline gas quality meets the California Air Resources Board's CNG vehicle fuel specifications. Also, there are several instances of home refueling applications being denied by SCG due to this issue. In SCG service territory areas like these, the NGV fueling infrastructure is limited by gas quality.

The development need is to devise a retrofit and/or fuel modification strategy to accommodate any legacy fleets that may encounter high-BTU gas. This process could also develop and provide a recommended gas specification to the ARB and gas utilities. Such a specification could allow for blending of diluents (e.g., nitrogen) or hydrogen to bring the gas into proper energy content range. This is a near-term need, because the legacy fleet will eventually go away through fleet turnover. Although retrofit kits are available for some specific legacy vehicles, not all legacy vehicles may have such an option available at this time.

Develop an Improved Composite Tank Safety Device / Installation Protocol to Avoid Rupture in Localized Fire

There have been a few incidents to-date involving a localized fire causing a rupture in an NGV composite fuel tank. The carbon fiber material used in composite tanks is not nearly as thermally conductive as steel tanks. In the cases where there has been a rupture, a localized fire ruptured tank material at one end of the tank before the relief valve sensed the heat or experienced a sufficient increase in pressure.

> RDD&D Gap: Need a sensing network on composite cylinders or some other means to avoid rupture by a localized fire that occurs away from the usual pressure relief valves and thermal sensors.

This has not been fully addressed by research, because it was not anticipated that one end of a cylinder could be engulfed in a fire while the other end not. The RDD&D need is to develop a sensing network on composite cylinders or some other means to detect a localized fire that occurs away from the usual pressure relief valves and thermal sensors.

Alternatively, ruptures could be avoided by adjusting the exterior insulation and position of composite tanks in NGVs. This would involve development of installation and insulation guidelines/standards, most likely based on simulation modeling and/or a failure effects and modes analysis (FMEA) that looked at the NGV as a system, and determine the best means to protect the composite cylinder from a localized fire.

Develop Improved Handling, Reliability, and Durability of Liquefied Natural Gas Dispensing and On-board Storage

LNG is stored on vehicles as a cryogenic liquid. LNG is the fuel of choice for many heavy-duty applications, especially long-haul and high-fuel-use trucking, because its energy density is far greater than that of CNG. However, users report splash-back, freeze-up, and vapor loss problems with LNG dispensing. Also the protective clothing requirement is more extensive with LNG—described as a “moon suit” compared to conventional fuels and CNG. The nozzle is deemed safe as is, yet protective clothing is still required. Before LNG can become a commercially viable fuel option for broader variety of heavy-duty applications, safe dispenser systems capable of providing leak-free, publicly accessible fueling must be developed demonstrated and deployed in the marketplace. Such an LNG dispenser will need to comply with performance standards that are currently being developed. Large-scale demonstrations and deployment activities—like the planned 5,300 LNG trucks under the San Pedro Bay Port Clean Air Action Plan—will be an opportunity to make progress toward a standardized commercial solution.

> RDD&D Gap: Develop ways to improve the handling, reliability, and durability of on-board LNG storage and dispensing in order to minimize the vapor return to station and to minimize the chances of vapor release.

RDD&D is also needed to improve the performance of LNG fuel containers with respect to long-term storage of fuel without allowing venting. Lower-cost systems also are needed. This is a very high priority with the California Air Resources Board (ARB) — they want to see venting from LNG tanks minimized/eliminated. This issue has at least two salient aspects:

1) Some vehicle LNG storage tanks have lost vacuum in service, which reduces heat insulation and leads to fuel venting. This can be resolved by improved tank manufacturing quality control and, if necessary, periodic inspection and maintenance.

2) Without additional storage technology breakthroughs, it appears practically impossible to store cryogenic liquids onboard for long periods of vehicle inactivity without venting. The current solution is to use LNG in vehicles that will not be out of service for long periods of time. This is true for most heavy-duty vehicles, and an LNG vehicle that will be out of service for an extended period will need to be de-fueled to avoid inevitable venting. Additional technology research and development into long-term storage methods and materials is needed to overcome this.

Provide GPS Guidance to NGV Fueling Station Locations and Details Statewide

> RDD&D Gap: need to develop system for NGV users with GPS-enable devices to be able to locate the nearest station, and obtain their public access information.

For NGV users that rely on publicly-accessible fueling stations, finding a natural gas station that is available for fueling at the time desired requires much more planning and effort than a conventional vehicle user. Given the rapid expansion of global positioning systems (GPS) and interactive displays into passenger vehicle/mobile communications devices, offering NGV users location-specific real-time updates, directions, and station information is now feasible in the near-term. Additionally, the information provided could include real-time station status updates, thereby avoiding trips to temporarily unavailable/out-of-service stations.

The infrastructure for collecting and distributing this information in real-time has not yet been set up for the NGV marketplace. Depending upon the frequency of information updates desired, this could be established using existing alternative fuel station maps and GPS-location services. If the real-time station update feature were desired, this would require stations to be equipped to allow online status reporting on a continuous/regular basis. In turn, the electronic networking of existing stations—which could also allow stations to adopt universal access and billing systems—would extend and enhance the range and convenience of NGVs.

Develop On-board CNG Storage with Improved Capacity and Design Features

> RDD&D Gap: Develop and demonstrate on-board lightweight, conformable, compact CNG storage at lower-pressure/higher-density.

Current on-board composite tank storage made from carbon fiber is lighter than conventional steel tanks, but the carbon fiber and the manufacturing process used to make such composite tanks are expensive. Developing advanced new material alternatives—including high-strength steels, aluminum alloys, and composites—that would lead to less expensive storage options without a significant weight penalty, would address this RDD&D gap.

As an additional alternative to current CNG and LNG on-board fuel storage methods, the NGV industry is investigating an improved low-pressure gaseous fuel storage system that uses lightweight composite storage containers filled with a variety of activated carbon. Natural gas is adsorbed on the surface of the carbon without any chemical change or bonding. The low storage pressure of adsorbed natural gas systems increases the potential to develop very lightweight, full-composite containers as well as conformable containers that would have better space utilization characteristics in vehicles.

For example, adsorbed natural gas tanks are being demonstrated in small applications in India and the Philippines, but viable options for the NGV market in the US still need to be developed and demonstrated. The University of Missouri—Columbia has been heading a project using carbon from corncobs, but at a laboratory/demonstration scale. If successful, this could allow transition away from high-pressure fuel storage systems, while storing more volume at much lower fill pressure.

Considerable research and development is still required to move adsorbed natural gas (ANG) storage into the commercial arena. Improved but less expensive carbons are the most obvious requirements. However, to support carbon development efforts a more in-depth study of the fundamentals of adsorption must be performed.

Ongoing basic research—such as the ongoing research and demonstration efforts at the University of Missouri-Columbia—is attempting to address the optimum pore size and surface conditions for methane storage, as well as the impact of the non-methane constituents of natural gas. Heavier hydrocarbons, odorants, water, and inert gases all have a tendency to reduce the storage capacity of activated carbons. Complete system integration and demonstration is required, as is a study of the long-term operation of the containers to help understand their degradation as a function of gas composition, filling cycles, and carbon degradation. As mentioned above, some examples of these are already being demonstrated in the marketplace, but only in a few applications.

Develop the Next Generation of Home Refueling for Light-duty NGVs

The current Phill™ home fueling system is deemed to be an adequate technology for the target market (sedan-size vehicles such as the Honda Civic GX). The issue here is the desire for a lower cost version/option. Also, a larger capacity would enable home fueling for larger vehicles with greater natural gas capacity, and fuel demand (e.g., large pick-up, SUV, or van).

> RDD&D Gap: Need to develop a home refueling device that can accommodate a broader range of vehicle sizes, while reducing costs. Also, deployment support for new home refueling devices; permitting, safety codes, and availability are potential hurdles in some locations.

For example, Honda has developed a home-fueling system for hydrogen to accompany its fuel cell vehicles currently under demonstration. Additional developments from this process as well as lessons learned from the current generation of Phill devices should feed into further development of this product.

Regions that do not have a history of light-duty NGV users with home refueling may lack procedures and standards for permitting Phill™ installation. Individuals that wish to purchase an NGV for personal use may encounter difficulty in getting timely acceptance for permits and/or approval for such installation. Although this is not a technical issue, it should be considered as part of the effort to deploy the home refueling device to the residential light-duty consumer.

Technical and Strategic Studies

Some suggested RDD&D program ideas seek to facilitate the priority ideas described above. One such effort is to conduct a forecasting study of post-2010 NGVs and their likely benefits, including a review of new/upcoming technologies and their potential to adequately enhance NGVs' ability to be a successful alternative fuel portfolio alternative.

Also, OEMs may not be fully aware of what particular NGV needs exist among potential and existing NGV fleet users. A web-based clearing-house for NGV needs and OEM/3rd party vehicle offerings would provide a centralized resource for compiling market needs that OEMs could then use to accurately identify which integration and development efforts to pursue. This would also serve as a valuable tool to policy makers and program managers interested in incenting such integration and development projects.

A valuable resource that could be revitalized to facilitate further information sharing about NGV market needs and solutions is the NGV Technology Forum that was sponsored most recently by the Department of Energy and the National Renewable Energy Laboratory, and operated by the Clean Vehicle Education Foundation. The purpose of the forum is to bring together stakeholders from all aspects of the NGV market to share insights to the barriers and solutions they have encountered.

NGV Technology Forum Revitalization Concept

Recent changes in offerings from the dominant heavy-duty natural gas engine manufacturer—including the discontinuing of three engines to be replaced by one large model—could lead to NGV user drop-outs from the market. The NGV Technology Forum could avoid future setbacks like these, and encourage broader viability of NGVs, by allowing manufacturers and NGV fleet users to communicate market needs and opportunities. Also, the Forum provides consensus guidance on implementation of NGV RD&D; aggregate fleet purchase requirements for specific NGVs including medium-duty and heavy-duty engine/chassis combinations.

The following stakeholders were originally included in the forum, although participation in the forum itself was generally open:

- National and State funding agencies
- NGV industry fuel suppliers, station owners/developers
- OEM and FSM companies
- Research providers
- National and State associations/coalitions
- Fleet owners, private and public

Appropriate goals for the revitalized Forum could be:

- Assess market needs and implement NGV RDD&D programs to meet those needs in cooperation with engine and chassis/platform partners
- Re-establish a much more robust needs assessment, prioritization and OEM/supplier liaison effort
- Pursue strategic RDD&D needs: (1) secure funding for engine, exhaust after-treatment, controls and related component RDD&D (2) define potential vehicles for development including specific performance criteria (e.g., Hp/torque), (3) identify potential OEM partners who will allocate development resources to bring these products to market.

Estimated Relative Costs of Priority Projects

Table 2 presents an early estimate of the expected costs of each priority project recommended. These estimates were the result of a group discussion and voting exercise by the stakeholder participants at the Asilomar Roadmap workshop in August 2007. These cost estimates therefore rely only on their professional experience and judgment, and provide only an initial idea of potential relative costs. Specific project planning and development will include much more detailed estimates of cost.

Table 2: Initial Budget Estimates for Priority PIER NGV Transportation Programs

Project Description	Estimated Cost
Engine Development and Vehicle Integration Recommendations	
• Integrate available natural gas engines into more models and applications by OEMs (all classes)	> $1 million
• Develop a broader range of heavy-duty NGV engine sizes and applications	> $1 million
• Develop a broader range of HDVs with improved engine economics, efficiency, and emissions	> $1 million
• Develop NGV HCCI engine technology	> $1 million
• Develop NGV versions of off-road applications	~ $1 million
• Develop a variety of hybrid natural gas HDVs	~ $1 million
• Develop engine technology optimized for HCNG fuel	~ $1 million
Fueling Infrastructure and Storage Recommendations	
• Develop on-board lightweight, conformable, compact CNG storage at lower-pressure / higher-density	> $1 million
• Develop legacy fleet engine controls and/or fueling infrastructure upgrades to accommodate fuel variability	~ $1 million
• Develop the next generation of home refueling for light-duty NGVs	~ $1 million
• Research an improved composite tank safety device / installation protocol to avoid rupture in localized fire	≤ $500k
• Develop improved handling, reliability, and durability of LNG dispensing and on-board storage	≤ $500k

CHAPTER 4: Sequence of Next Steps

Broadening the Perspective on RDD&D

Chapter 3 described the major NGV research and development needs, and suggested an initial estimate of priority sequencing of those needs within each of three RDD&D categories: engine development and vehicle integration, fueling infrastructure and storage, and technical and strategic studies. This information is vital for understanding the most pressing needs, but by itself it is not a roadmap to NGV success. RDD&D investment choices will be particularly influenced by the need to remove the most difficult barriers to NGV use as well as to encourage RDD&D investment by others. A broad range of other activities will be required for NGVs to overcome those barriers, reach the market effectively, and gain momentum toward achieving their full potential role in a future portfolio of alternative fuel vehicle technologies.

This chapter identifies those activities and ways in which they can interact with each of the identified RDD&D opportunities to provide a complete pathway to success. Some key aspects of a complete roadmap include the following:

Dynamic quality. Such road-mapping is not a static one-time activity. The Roadmap provides a starting point, but as future events unfold both new opportunities and barriers will appear. An ongoing process of roadmap review and updating should be a central feature of NGV RDD&D management. Included is a recommendation for creation of a standing advisory board, perhaps in concert with other potential sponsors such as US DOE/NREL, to monitor industry developments and provide periodic recommendations on new technology opportunities and priorities. This updating and re-prioritizing process is an essential tool in keeping the overall NGV RDD&D program current in an ever-changing context of events.

Downstream activities. Public agency RDD&D programs such as PIER are sometimes restricted to technology innovation and enjoined from "downstream" activities such as demonstrations and deployment activities such as market assessments and strategies. However, in addition to original innovative research and development, NGV demonstration and deployment initiatives are crucial in the mapping of pathways from laboratory to market. In particular, efforts to encourage targeted large-scale demonstrations are key to creating market pull for new products. Investigation of the most effective means for doing this is itself a valuable potential RDD&D opportunity.

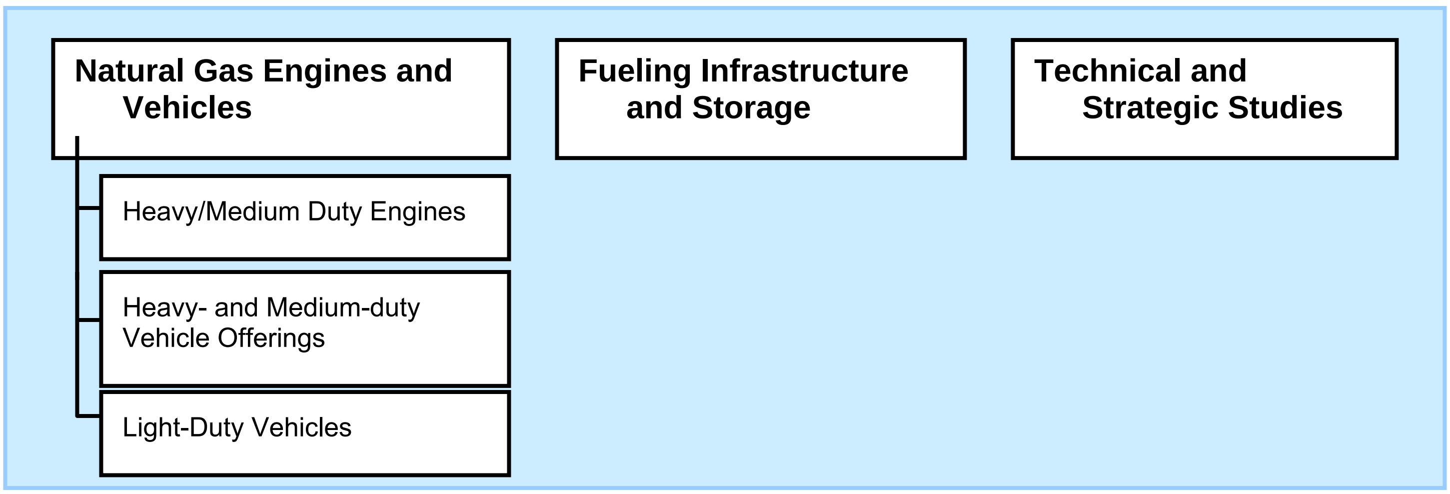
Supporting activities. A broad range of supporting activities must be integrated into any technology innovation activity in order to assure momentum from laboratory to market. These activities are generally not technical, and include different efforts at each stage of a product's progression from development through various stages of testing, demonstration, production, marketing, and deployment. In the Roadmap, such supporting activities are outlined only as examples; each product will require a planning effort to anticipate barriers at each stage and identify the specific supporting activities needed. That product "business plan" is an essential part of the RDD&D process, whether or not the supporting activities are part of the original innovation's development.

RDD&D Sequencing and Coordination

The previous chapter described a model and activities generally required to maximize the chances of moving a specific innovation into production and market acceptance. But a larger issue must also be addressed: how to sequence, combine, and coordinate the individual product development and marketing strategies into an overall roadmap?

At this stage in NGV RDD&D planning, it is appropriate to describe the roadmap in terms of strategic steps for implementing ideas from each major program category. The RDD&D categories are shown graphically in Figure 3 and represent the major RDD&D needs described in Chapter 3. This chapter presents those recommended strategic sequences, and the following and final chapter presents a recommended division of the key RDD&D elements into early, mid-term, and later sequencing.

Figure 3. Three Major RDD&D Categories Described in the NATURAL GAS



VEHICLE RESEARCH ROADMAP

Heavy and Medium-Duty Engine Development

For the heavy- and medium-duty engine development priority ideas, the recommended strategy begins with existing natural gas engine offerings and moves on systematically to additional engines to broaden the NGV market.

a) Support cost and performance improvements to existing engines to improve the competitiveness of the NGV option.

b) Develop additional heavy-duty and medium-duty engine size options to allow a broader range of vehicle types and sizes.

c) Assist in emissions testing and certification for any new natural gas engines and vehicles, in collaboration with the California Air Resources Board.[8]

d) Eventually develop large engines for off-road, rail, and marine applications.

e) Eventually develop advantaged engine technologies, such as HCNG and HCCI

Heavy-duty and Medium-duty Engine/Vehicle Integration and Offerings

This topic includes both CNG and LNG variants. CNG technology is broadly applicable to many urban-area heavy-duty and medium-duty uses, while LNG is likely to be focused primarily on heavy-duty long-haul intercity trucks and others with very high daily mileage due to fuel tank volume constraints. Port container mode transfer tugs are examples of the urban market.

a) Collaborate with OEMs to provide more integrated engine/chassis options for EXISTING engines, and support that with business-case development to prove value of the natural gas option to OEMs.

b) Conduct visible demonstration tests of existing and new OEM natural gas vehicle offerings in real applications (actually two tracks, one soon for existing NGVs and another later for new ones) with substantial technical and economic analysis and fleet-targeted publicity of the results.

c) Entry of all existing and new vehicle choices into a public-accessible database for users to match against their requirements and request others, thereby facilitating orders and demonstrating additional demand to OEMs.

d) Further vehicle integration with newly developed engine sizes, providing more vehicle market choices.

e) Integrate NGV engine technology into off-road, rail, and marine vehicle applications.

f) Ongoing deployment support for ALL available vehicles in the form of publications, Web information, conference presentations, and trade show exhibits.

Light-Duty Vehicle Development

The Roadmap process resulted in the conclusion that most technical issues for light-duty NGVs are being handled effectively by the automakers. One firm (Honda) is currently active in the US market with a single small sedan (Civic GX). Clearly more models are needed to meet a reasonable range of market needs. However, many other OEMs routinely produce and market large numbers of other models in Europe, Asia, and elsewhere. At some point of public interest, those OEMs could relatively easily transfer their NGV capabilities to the US market. At present, the light-duty market is small and focused heavily on centralized fleets.

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[8] Natural gas heavy-duty applications and larger medium-duty applications certify by engine. Light-duty vehicles are certified by vehicle. Light-duty conversions are certified by vehicle. Medium-duty vehicles (8,500 to 14,000lbs GVWR) have an option to be certified either way. Diesel engines between 8,500 and 10,000 GVWR that are passenger vehicles must be vehicle certified; those that are commercial may be engine certified.

a) Further develop the current LDV market through education, technical assistance, and evolutionary cost reductions

b) Assure that fueling infrastructure expansion accommodates LDVs and provides maximum public access and convenient standard protocols.

c) Encourage more manufacturers to introduce additional vehicle choices, based on evidence of the expanding market and infrastructure.

No major technical issues were identified as needing PIER or other public sector RDD&D support. However, a broad range of supporting activities (codes, incentives, demonstrations, infrastructure, public education) could be undertaken or assisted by such public sector organizations.

Natural Gas Vehicle Infrastructure

The Roadmap envisions the key strategic efforts for NGV infrastructure to emphasize expansion of fueling locations and maximum usability of all fueling stations.

- Optimize fueling infrastructure access through online, print, and GPS station locator capabilities as well as simplified universal credit card authorization
- Improve fueling infrastructure convenience, including number of stations; handling, durability, and reliability
- Reduce station cost through standardization
- Remove barriers to transitioning to and utilizing natural gas fueling
- Reduce cost and improve conformability of on-board natural gas storage options
- Address fuel contamination and composition issues

Technical and Strategic Studies

A variety of activities can serve to help organize and coordinate the entire NGV development and commercialization process. The Roadmap envisions the key strategic activities to be the following:

- Creation and operation of a roadmap advisory council to inform updating of the roadmap as circumstances and opportunities change.
- Provision of technical success information to legislators and regulators in support of NGV industry and environmental advocates' efforts at new legislation and regulatory policies.
- Technology forum to bring together stakeholders from all aspects of the NGV market to share insights to the barriers and solutions they have encountered

Priority Sequencing of Major Activities for Funding

The strategies for each key NGV program element as just presented combine to suggest which Roadmap recommended projects should be begun with initial funding support. Those projects should be undertaken with coordination among sponsors in order to optimize total resources, minimize unproductive duplication or conflicting efforts, and maximize collective progress. The recommended staging of projects can be depicted through a table of three priority groupings, as shown in Table 3. These initial sequencing recommendations should be reviewed and revised to reflect changing conditions and needs as the NGV advancement process continues.

Table 3: Recommended Funding Priorities

Top Priorities	Second-Tier Priorities	Longer-Term Priorities
Existing heavy-duty and medium-duty engine improvements		HCNG and HCCI engines/verifications
Heavy- and medium-duty engine/vehicle integration for CNG	Heavy-duty engine/vehicle choices for LNG	Light-duty vehicle choice expansion
Existing vehicle demos	Demonstrations of new vehicle choices	
More heavy-duty and medium-duty engine sizes	Certification of new models	Continued engine refinements
	On-board fuel tank economies	Low-pressure on-board fuel storage
Fueling station economics	Modular fueling stations	Non-traditional station siting
Fueling ease/standards for CNG and LNG	GPS-based station locator/information portal	
Fleet business case models	Public station economies	Insurance economies
Technical roadmap update panel		
CNG & LNG vehicle database	Codes and protocol studies/changes	
Develop legacy fleet engine controls and/or repower/retire programs to accommodate fuel variability	Determine and develop controls for emissions due to fuel variability and stricter GHG (i.e., methane) standards.	

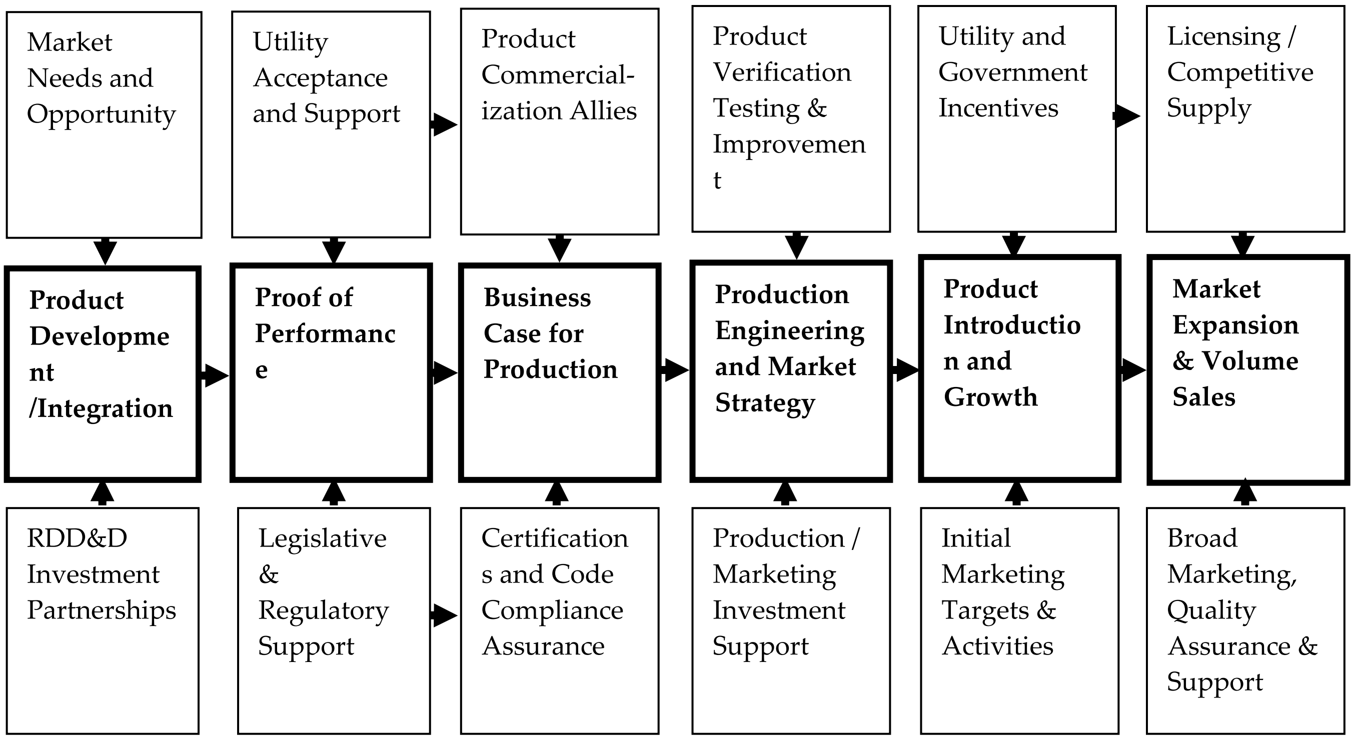
Moving Each Innovation from Laboratory to Market

Much more than research and development is required for NGVs to contribute effectively in the market to goals for reduced oil consumption, emissions, and climate protection. In that broader effort there are many opportunities for the state to play important supporting roles in collaboration with industry. In this chapter we describe a general roadmap model for moving NGV innovations into production, market introduction, and adoption. That model encompasses a variety of activities, including the following examples.

- Broad industry involvement in RDD&D planning and review
- Limited licensing of technology innovations to developer
- Operational testing of RDD&D products
- Detailed market assessments and preliminary business cases
- Transfer into manufacturer prototype versions
- More visible testing and field demonstrations, with results publicized
- Development of advocacy allies, regulatory support, incentives
- Manufacturer business cases development and engagement
- Support of manufacturer production design and engineering steps
- Market development and rollout strategy planning
- Testing and demonstration of initial production-engineered products
- Field demonstration and quality assurance testing
- Certification if required
- Final production engineering, production planning, and tooling
- Marketing initiatives to initial targets
- Market feedback and product/marketing refinements

These activities can be combined and organized graphically to demonstrate the overall process and its interactions. Figure 4 provides an illustration of the broad range of activities to be considered in planning an integrated development and market connection process for each NGV RDD&D product.

Figure 4: Range of Activities for Integrated Development and Market Connection



The boldface activities shown are the principal elements in a product development sequence. The other activities illustrate the broad range of supporting activities that must be considered and included as needed to assure that each of the principal steps is successful in advancing the product toward the market.

This general model is applicable to each individual RDD&D product. For optimal success, each RDD&D innovation should be accompanied by a comprehensive strategy that considers and refines that general model's activities for applicability. In this Roadmap such a level of detail for each of the many recommended RDD&D goals would be impractical as well as premature, but the development of those product-specific strategies should be a key part of every RDD&D effort.

The various supporting activities within each product strategy may be undertaken by a variety of participants from public agencies, regulatory bodies, and gas utilities to entrepreneurial developers, trade associations, private foundations and major OEMs. These efforts may be either alone or in collaboration.

CHAPTER 5: Conclusion

The Roadmap provides a comprehensive analysis of NGV RDD&D needs, primary and supporting activities, and priority-setting. This is a broad perspective: Findings and recommendations are not limited to opportunities for the Energy Commission's PIER program, although guidance to PIER is a major purpose of the Roadmap. PIER management will necessarily select appropriate Roadmap activities in collaboration with other RDD&D sponsors.

This roadmap is only a benchmark, since time passes and circumstances change. However, it provides a solid foundation for regular review and updating in light of changing needs, RDD&D results, and specific opportunities that cannot yet be predicted.

A number of conclusions can be drawn concerning this roadmap process and its results:

- The Roadmap development process has resulted in a comprehensive array of key technical recommendations, including a broad range of RDD&D activities needed to ensure that NGVs remain a viable and increasingly valuable alternative transportation option in California. The Roadmap also emphasizes the need for integration of a broad range of supporting activities that are essential to achieving successful production, market entry, and broad acceptance of NGV innovations.
- The Roadmap's recommendations serve the needs of key policies and programs related to alternative fueling infrastructure, including California's public goods RDD&D program (PIER) for natural gas as well as other California legislative mandates on alternative fuels and vehicles, such as AB 1007 and AB 118. The Roadmap's results also suggest opportunities for NGV technology and commercialization advancements by private industry and other key actors in the RDD&D process.
- The broad vision of RDD&D for NGVs and fueling infrastructure focuses first on HDV fleet applications, with emphasis on broadening that market and enhancing NGV value. As additional engines, infrastructure, vehicle options, and applications are expanded through RDD&D activities, medium duty truck and bus markets are the next RDD&D targets. As infrastructure further develops, light-duty NGVs—for which most RDD&D tends to be conducted by their manufacturers—will gain market value and scale both as a significant contributor to petroleum reduction and a fuel cell vehicle precursor. Off-road, marine, and rail applications of NGV technology are also potentially valuable but at a lower priority due to smaller potential impact on key alternative fuel goals.
- The Roadmap represents the views of a broad range of stakeholders. We invited participation by over 100 stakeholders in the NGV market and conducted more than 35 in-depth interviews representing the interests of the NGV industry, government, advocacy groups, fleet users, and utilities. The responses of these stakeholders are summarized in Appendix Tables 6-1 through 6-3. These reviewers and others also provided feedback on drafts of the Roadmap. Finally, stakeholders at the Roadmap Asilomar Workshop held in Pacific Grove in August 2007 were asked to review, refine and prioritize the many NGV RDD&D ideas collected during the earlier interviews, and the results were offered to all stakeholders for comment.

- AB 118 was signed into law late in the Roadmap 's development (October 2007), adding substantial new funding and authority for a broader range of alternative transportation fuel activities than is the case for PIER. AB 118's passage therefore substantially increased this roadmap's value and scope. In addition to providing additional State support, AB 118 will also attract additional interest from industry in collaborating on future NGV RDD&D projects.
- In addition to technical RDD&D innovations, this roadmap notes the vital importance of supporting activities that foster advancement of such innovations from laboratory to production and market acceptance. Each innovation requires a variety of supporting elements, ranging from regulatory compliance, business cases, and production engineering to marketing strategies, early adoption incentives, and market education.
- California is not an island; the Roadmap's recommendations are broadly applicable nationally. This state's RDD&D priorities for NVG technology are important inputs to all NGV advancement efforts elsewhere. The current surge of California policy regarding alternative transportation fuels and technologies may give rise to a renewed interest and potential collaborative or complementary efforts on the national level for NGV RDD&D programs.
- Overall, ongoing coordination of public and private RDD&D in the NGV marketplace is needed in order to ensure NGV viability both in the near- and long-term. Innovative coordination mechanisms, such as the Roadmap's proposed national NGV Technology Forum, will enhance the industry's communication of market needs between users and suppliers, and thereby offer reassurance to all stakeholders of the viability of this important technology.

APPENDIX

NGV Market Stakeholder Inputs

The main body of this document is focused on identifying those NGV technologies that, if addressed, would be expected to provide a significant benefit to the NGV Market. In preparing this document, NGV market stakeholders were asked to share their perspective on NGV-related technological hurdles. This Appendix contains a summary of these responses received as of August 2007. A summary compilation of responses is provided in Tables 1 and 2, as summarized in the NGV Gap Analysis performed as part of the Roadmap development.[9] Table 3 lists the inputs provided by stakeholders during interviews for the Roadmap development. This list was presented to NGV stakeholders for comment at the Asilomar Roadmap Workshop in August 2007.

NOTE: The Roadmap includes topics related only to vehicles and infrastructure, not fuels. Fuel compositions and other supply issues upstream of fueling stations are not included in the main body of the document. Priority RDD&D ideas were discussed in Chapter 3, and educational/marketing programs and other supporting activities were discussed in Chapter 4. In order to convey the breadth of input provided by NGV stakeholders, a summary of all NGV stakeholder input received during Roadmap development is shown in Table 6-3, including any otherwise out-of-scope ideas related to NGV RDD&D. Inclusion of the comments below do not indicate a preference or implication on the part of the PIER program that such projects will or should be awarded PIER funding.

Table 1: Engine Development and Vehicle Integration RDD&D Gaps not yet Sufficiently Addressed, as Determined from a NGV Gap Analysis

Need to integrate, demonstrate, and deploy additional medium- and heavy-duty applications / OEM vehicles—such as, shuttle buses, street sweepers, utility trucks, and pick-up and delivery trucks—to be able to offer engines capable of meeting future emissions standards.
Develop, demonstrate, and deploy larger horsepower/displacement (e.g., 400-600 HP range, 12-16L displacement) natural gas engine offering(s) suitable for heavy-hauling and/or off-road applications such as waste transport, coal hauling, and semi-tractor trailer applications; this would allow NGVs to serve more high-fuel-consuming transportation markets.
Develop inexpensive methane/ethane/propane catalyst to ensure GHG benefit vs. diesel

[9] The NGVRR Gap Analysis used stakeholder input and a literature review of NGV research and development to determine which RDD&D needs had not been adequately addressed to-date. These needs were considered the RDD&D “gaps” that remain as barriers to full deployment of NGV technologies in the marketplace.

Table 1: Engine Development and Vehicle Integration RDD&D Gaps not yet Sufficiently Addressed, as Determined from a NGV Gap Analysis (continued)

Develop a broader range of heavy-duty NGVs with improved engine thermal efficiency. Historically, heavy-duty NGVs (with SI, throttled natural gas engines competing with compression-ignited, unthrottled diesel engines) have an overall fuel economy penalty relative to conventional vehicles (especially at idle and low loads), which is a significant barrier to serving as a broadly viable alternative transportation fuel. Some heavy-duty engines have made advances—Westport HPDI engines provide diesel efficiency and CAT/CAP dual fuel engines provide intermediate efficiency—but not yet for all horsepower/displacement ranges.
Need to deploy a broader range of light-duty NGVs in the domestic market—one option is to review viable means for bringing foreign models/designs to the US. Foreign versions of NGVs are experiencing large growth, with recent announcements from India, Pakistan, and other countries around the world regarding additions of thousands of NGVs to their taxi fleet and mass transit system. These increases are a mix of conversions and OEM vehicles. Conversions are available domestically, however they must be certified for use by EPA and ARB in California—the latter, a reportedly challenging process that must be undertaken for each engine/vehicle model combination. In addition to uncertainty of market demand, different safety and emissions certification standards, along with different incentives and mandates, serve as barriers to foreign light-duty NGV models in the US
Port/off-road vehicle types, such as yard tractors and crane transports, need to be designed to accept natural gas engines (e.g., higher heat rejection loads need to be accommodated and existing equipment designs need to be modified in order to integrate these engines.). LNG-fueled yard hostlers are currently under demonstration at the Port of Long Beach; no port vehicles are in the deployment phase.
Methane emissions from NGVs are currently unregulated, but as GHG emission standards are rolled in, methane will be very important to control. As NGVs are designed to emit less NOx, methane, ethane, and propane emissions tends to go up. There is a need to address this through injector technology, combustion technology, and exhaust emissions control technology. Need to develop and demonstrate catalyst formulation than can oxidize methane, ethane, and propane, as opposed to diesel catalysts formulated to oxidize heavier hydrocarbons (i.e., those molecules with ~10-15 carbon atoms).
Future emissions concerns: toxicity of natural gas exhaust emissions may become an issue as lower PM standards tend to drive up formaldehyde emissions (in diesel vehicles). Need to determine how well future NGVs will control toxics (e.g., formaldehyde) emissions better than diesel. Also ultra-fine PM (PM0.1) may be found to be more harmful than larger PM—will NGVs be able to control PM0.1 better than diesel vehicles? Where does PM0.1 originate in NGVs (e.g., lube oil, fuel, or the combustion)
Develop, demonstrate, and deploy hybridization in for applications with most promise (all classes).
Develop HCNG options that increase vehicle fuel efficiency and reduce emissions from legacy fleet. This may incorporate an engine retrofit and/or engine control reprogramming.
Develop natural gas auxiliary power unit (APU) powering on-board equipment in natural gas-based vehicles. This will become important for applications--such as utility trucks and long-haul trucks--that use APUs for supporting loads while the vehicle is not in operation.
Confirm fuel variability tolerance, specifically in stoichiometric EGR heavy-duty engines, to maintain emissions
HCCI development across all engine sizes. Demonstrations of gasoline-powered LDVs are underway—other engine sizes and types are still under the research and development phase

Table 2: Fueling Infrastructure and Storage RDD&D Gaps not yet Sufficiently Addressed, as Determined from a NGV Gap Analysis

Commercially viable way to detect contamination and/or changes in gas composition in real time from station pipeline supply and in pressurized fuel stream. Only integrated sampling (i.e., a sample collected over time) is commercially available, which fails to allow for real-time response/adjustment to presence of impurities. Prototype equipment for real time analysis and control is available and could be demonstrated for NGV applications.
Deployment support for new home refueling devices; permitting, safety codes, and availability are potential hurdles in some locations.
Hydrogen-CNG blends (HCNG)—what combinations work under which real-world conditions; which combinations would achieve best performance and durability? Studies have looked at HCNG operation under laboratory and limited on-road trials, but have not yet investigated full HCNG demonstration and deployment over a wide range of real-world applications.
Develop and demonstrate reliable oil-free compressors that are viable alternatives to conventional compressors. Current oil-free compressors offer a low-contaminant alternative to conventional compressors, but are problematic in operation and maintenance.
Develop small cogeneration in garage that incorporates home refueling device, thereby expanding the overall efficiency and utility of the device.
Develop software/online tool for analyzing real-time capacity of CNG stations, and making information to end users, so as to prevent overloading station.
Standardized nozzle and receptacle for LNG fueling that reliably avoids leaks, freezing, or splash backs, and includes safe breakaway features. These are needed to reduce system cost and will improve consumer safety, eliminate/minimize the need for protective clothing, and enhance consumer acceptance. The SAE Alt Fuels subcommittee is drafting a recommended practice on LNG nozzles but needs support to complete the work.
Technology to eliminate oil carryover from natural gas compressor to vehicle. Oil blow-by has been a problem at some stations; adding filters help that problem, but such filters must be monitored and changed out periodically. Developing a reliable and robust means of preventing carryover to the engine is needed, regardless of amount of oil blow-by at the station.
Viable combined LNG/CNG/HCNG station; there have been demonstrations of pairs of fuels, but the trio of fuels has not been deployed commercially.
Need to review cost-benefit of higher storage pressures for station (like the 5kpsi, 10kpsi used for hydrogen storage) and vehicle (5kpsi), given that this would increase the fueling capacity at the station and on-board the vehicle. Higher pressures for natural gas (over 3.6kpsi) has been considered and rejected due to large increases in compression work to store less and less additional energy—need to determine if there are any alternative technologies that would made this economically feasible.

Table 2: Fueling Infrastructure and Storage RDD&D Gaps not yet Sufficiently Addressed, as Determined from a NGV Gap Analysis (continued)

Develop ways to improve the handling, reliability, and durability of on-board LNG storage and dispensing in order to minimize the vapor return to station and to minimize the chances of vapor release. This involves both the vehicle fuel system and the station. This will become more important with larger number of applications, and where the controls needed for smaller dedicated fleets may be more difficult to achieve.
Develop and demonstrate on-board lightweight, conformable, compact CNG storage at lower-pressure/higher-density. As one example, adsorbed natural gas tanks are being demonstrated in small applications in India and the Philippines, but viable options for the light- and heavy-duty market in the US still need to be developed and demonstrated. (also described in Table 4.1) Or, Develop low-pressure adsorption tank (for all classes), which ideally will be able to store more volume at much lower fill pressure. The University of Missouri has been heading a project using carbon from corncobs, but at a laboratory/demonstration scale. If successful, this could allow transition away from high-pressure fuel storage systems (gap also described in Table 3.2).
Need to develop standard practices for properly installing and insulating composite tanks and deploy this among future vehicles to avoid rupture from localized fire exposure. There have been failures in which the Pressure Release Device (PRD) failed to open before the composite tank ruptured. Better understanding is needed from a system point of view on how tank installation, position, and insulation may subject it to fire danger. This may include a Failure Modes and Effects Analysis and/or modeling of under what circumstances is the composite cylinder system most vulnerable. Composite tanks have low thermal conductivity, thus rendering pressure relief and thermal relief valves useless if the heat from the fire never comes near the valve. Investigators from past accidents found that the tank wall was exposed to a fire in a localized position far from PRD, and thus the material failed before sufficient heat from the fire could reach the interior of the tank and increase the pressure beyond the PRD limit.
Additional research is needed to develop improved compressors for conventional public-access stations/larger heavy-duty operations, as well as home fueling. Compressor durability and reliability can be improved. Better controls are needed to reduce electrical operating costs and better manage vehicle fill operations. Typical three- and four-stage reciprocating compressors are expensive to service and maintain. Better materials and/or designs could materially improve service and maintenance performance. Alternative compressor technologies (e.g., hydraulic compressors) optimized for cost and performance could satisfy needs in a rapidly expanding market
Lower cost station peripherals (e.g. dryers and dispensers) would help provide a more- competitive low-priced fuel. Improved dispenser technology to communicate with the vehicle and compressor to make sure a full fill is achieved would improve CNGV range and reduce the need for frequent fueling, making NGVs a more convenient choice. Communications protocols need to be standardized for all vehicles. Lower-cost metering (e.g., volumetric metering), and real-time gas quality sampling would also tend to reduce barriers to NGV market growth.

Table 3: Summary of NGV Market Stakeholder RDD&D suggestions and Ideas Provided During Roadmap Development

Advanced Technology Development
• SOFC-APU using natural gas • Hybridization to expand application of current engine hp range • Fuel variability tolerance, specifically in stoichiometric EGR heavy-duty engines to maintain emissions performance • HCCI development for MY2010+ • Making consistent HCNG blends and developing corresponding metering and sampling equipment • Using biodiesel pilot in dual fuel engines • Inexpensive methane catalyst to ensure GHG benefit vs. diesel • 400hp (i.e., greater HP and displacement) engines • Gas adsorber storage technology
Demonstration, Data Collection, and Deployment Topics
• Demonstrate and deployment support for using bio-methane • Demonstrate and deployment support for using HCNG-blends • Demonstrate and deployment support for hybridization • Demonstrate and deployment support for new home fueling devices
Engine Development
• Funds for MY2010-compliant engines • Stoichiometric engines • Lower cost/weight medium-duty and lighter heavy-duty engines based on gasoline, rather than diesel, designs • Larger horsepower/displacement range (450hp)/12-13L & 15L • Accommodate applications with higher heat-rejection loads to expand to other on- and off-road applications (port, utility, delivery trucks) • Develop injector, combustion, control technology for controlling methane emissions • Develop HCNG options to remain significantly lower than current emission standards • Improve certification process (make less costly) for small-volume manufacturers • Aftertreatment for MY2010+, how to deal with PM0.1 • Support both retrofits and new engine platforms

Table 3: Summary of NGV Market Stakeholder RDD&D Suggestions and Ideas Provided During Roadmap Development (continued)

Fuel Storage
• LNG storage containment including reliability and durability, • Conformable tank configurations, • Acceptance/certification/codes for using composites for fueling station ground storage applications, • Ways to handle LNG to minimize need for vapor return to station/vapor release, • Higher storage pressures for station (like H2's 5kpsi, 10kpsi) and vehicle (5kpsi), • Pressure relief and thermal relief valves on lower-thermally conductive composite tanks may leave tanks susceptible to rupture from localized fires (i.e., with a hot point focused away from a relief valve); can address through tank design/materials, storage costs, tank manufacturing costs (for carbon-fiber). • Adsorber technology--need lightweight, compact storage, at lower pressure, and at higher density on-board
Fueling Infrastructure **(See "Fuel Specification" section below)**
• Consistency in natural gas supply: quality specifications vs. wide variations in real-time gas quality/contamination (and impact on emissions)-- only integrated sample reasonably available, there's no way currently to do this in real time • Technology needed to tackle oil carryover from compressor to vehicle (in applications using pipeline gas—this is not an issue if using LCNG process to deliver CNG) • Equipment for testing the oil concentration in the pressurized outlet • Develop standardized nozzle and receptacle for LNG, avoiding leaks, freezing, splash-backs to reduce system costs and enhance safety/acceptance • Deployment support for new home refueling devices • Validate operational performance and durability • Breakaway (safety) device for LNG fuel • Tool for analyzing capacity of CNG stations to prevent overloading station • Demonstrate that ground storage service conditions are relatively benign compared to other pressure vessel applications, thus demonstrating that ground storage service is safe for composite technologies • Foster small scale production/liquefiers • Oil-less compression—need to bring down cost • Small cogeneration in garage • Site a combination of LNG/CNG and HCNG at a station • Improve compressor reliability and durability; reduce electrical operating costs and service/maintenance needs

Table 3: Summary of NGV Market Stakeholder RDD&D Suggestions and Ideas Provided During Roadmap Development (continued)

Vehicle Integration
• Where NGV engines and chassis could be integrated on the OEM assembly line, it would be more cost effective • It's costly to test, certify, and go through these mandated procedures • Without being OEM, retrofitters have no access to vehicle computer. It's a hurdle to bypass/modify OBD software. • The fuel gage doesn't give a reliable read of LNG fuel left and this leads to stranded vehicles • Also, unreliability of the engines, maintenance level is higher, so need better reliability • There needs to be a national focus on after-market conversions—it would be nice for $ to go towards developing more conversions for more platforms
Codes and Certification
• Working with auto industry/state legislature to convince ARB to allow conversions more latitude • Ease expensive testing requirements for conversions • Demonstrating that composites are appropriate for ground storage-- most local codes don't cover composite cylinders, so would need to look at updating codes and standards
Fuel Specification / Exhaust Emissions
• Do impurities in gas supply need to be removed for NGV use? • The emissions may pose health risk, especially for home fueling (e.g., what to do with the ethane in the gas?) • Toxics emissions (formaldehyde and ultrafine PM (PM0.1) from combustion) from natural gas combustion may be significant • To some extent, the infrastructure in the SoCal Gas service territory is being somewhat limited by gas quality. SoCal Gas has been limiting new station growth based on pipeline gas quality meeting the CNG motor vehicle specifications. Also, there are several instances of home refueling applications being denied by SoCal Gas due to this issue. • Determine natural gas fuel composition requirements for heavy-duty engines meeting 2007-2010 emission regulations,, then, characterize fuel composition tradeoffs affecting the three generations (older open-loop lean-burn (the "legacy" fleet), newer closed-loop lean-burn, and future stoichiometric three-way catalyst engines) of heavy-duty natural gas engines, and then recommend a natural gas quality specification that provides the optimum benefit balance for California. • Removal of propane and other hydrocarbons from natural gas at fueling stations, so as to put essentially pure methane in vehicle fuel tanks. This would significantly increase the fuel efficiency of NGVs (of interest independently of natural gas storage) and at the same time lower costs of ANG tanks because no on-board removal of non-methane hydrocarbons would be needed.

Table 3: Summary of NGV Market Stakeholder RDD&D Suggestions and Ideas Provided During Roadmap Development (continued)

Product Variety
• Development funds, or even an investment opportunity would be needed to increase the market • In order to place the European vehicles in CA market, to what extent does it require reprogramming the engine/the fuel system management? What changes are needed to meet US safety requirements?
Other Comments
• CEC agencies (ARB, EPA, and AQMD) partner on more projects to certify engines in many different size (class) applications • Third party companies (Baytech, Emissions Solutions, BAF, etc.) need assistance in the certification process • SCG would like research to have real, demonstrable applications, not computer model assessments (forecasting models) or white papers • Land fills and Dairy Farm applications may be key new markets yet un-served by the CNG industry that may leverage more engine types and keep the NGV industry alive during these competitive times • Need to establish extended range goals for different classes of vehicles. Then the researchers are free to reduce vehicle weight/drag, increase tank size, increase the capacity of the tank, increase engine efficiency, increase energy density of the storage media, or find imaginative places to add more tanks. An overall range goal is critical for the success of NGV's. • The type of research we are proposing for PIER is research with public monies that would allow manufacturers to pursue more aggressive approaches to technology development for their own products -- or develop technology paths in a pre competitive technology arena that would benefit others getting into the market.

Participating NGV Market Stakeholders

The comments listed in Tables 1 through 3 were taken from communications and interviews with the NGV market stakeholders listed in Table 4.

Table 4: NGV Stakeholders Participating in Interviews

Bill Calvert, BAF Technologies
Annmarie Mora, Andrew Yoon, Dipak Bishnu, and Gary Yee, California Air Resources Board
Peter Ward, Ray Tuvell, and Gary Yowell, California Energy Commission
Mike Eaves, California Natural Gas Vehicle Coalition
Jim Harger, Clean Energy
Hank Seiff, Clean Vehicle Education Foundation
Richard McNitt, CSA America
Doug Horne, Doug Horne LLC and Clean Vehicle Education foundation
Scott Baker, Cummins-Westport
Dennis Smith, Department of Energy
Rick Slama, AFV specialist, DGS (Office of Fleet Administration)
Jim Burkhart, Emission Solutions
Ron Eickelman, FAB Industries
Erik Neandross, Gladstein, Neandross & Associates
Bill Liss, Tony Lindsay, Lou Lautman, GTI
Gunnar Lindstrom, Honda
Kate Blumberg, International Council on Clean Transportation
Rob Mercer, IMPCO
Rich Kolodziej, NGV America
Tom Alexander, Jim Larson, and Bill Zeller, PG&E
Craig Webster, Powertech Laboratories
Jim Dong, Raymundo
Matt Miyasato, SCAQMD
Ed Harte, Mike Landau, Cherif Youssef, Sempra (Southern California Gas Company)

Roger Hooson, SFO
Charles Powars, St. Croix Research
Mike Jackson, TIAX
Jennifer di Tapia, Trillium
Charlie Ker and Richard Ancimer, Westport Innovations
Richard Parish, Weststart

*John Urkov represented by Andrew Yoon (ARB)

PIER Project Screening Criteria

It is likely that PIER's best strategy will be to leverage its limited funding through co-funding of high-risk/high-payoff RDD&D with other key industry players who would be encouraged to invest because of PIER's contribution. Such selections will be based on the PIER investment criteria dictated by PIER policy in Figure 1.

Figure 1: PIER Public Interest Screening Criteria

Test 1	**Energy services and products that provide benefits to California ratepayers and citizens**	**TEST PASSED IF ANSWER IS "YES" TO ANY QUESTION** Does the research seek to improve the affordability of electricity or natural gas services and products? - or - Does the research seek to improve the safety and/or reliability of electricity or natural gas services and products? - or - Does the research seek to reduce the impact on or restore the environment through electricity and natural gas services and products?
Test 2	**Transportation Research activities**	**TEST PASSED IF ANSWER IS "YES" TO ANY QUESTION** Does the research seek to improve transportation energy efficiency? - or - Does the research seek to reduce greenhouse gas emissions or reduce health and environmental impacts from air pollution related to electricity and natural gas production and use? - or - Does the research seek to increase the use of alternative fuels?
Test 3	**Developing technology and advancing scientific knowledge**	**TEST PASSED IF ANSWER IS "YES" TO EITHER QUESTION** Does the research effort develop, demonstrate, or help to commercialize new or improved technologies[1]? - or - Does the research advance scientific knowledge upon which new technologies, services, products, or policies can be developed?
Test 4	**Research not adequately provided by the competitive and regulated markets**	**TEST PASSED IF ANSWER IS "YES" TO EITHER QUESTION** Is the research focusing on science or technology that would otherwise not be developed during the desired time frame for the intended application? - or - Is the research addressing a public need for which there is insufficient research activity in competitive and regulated markets?

Source: California Energy Commission

[1]Technology includes hardware, software, systems, exploratory concepts, and supporting knowledge.

AB 118 Project Requirements

The objectives and scope of the AB 118 legislation are:

- Deploy alternative fuels and advanced vehicle efficiency technologies
- Emphasize technology deployment and commercialization
- Emphasizes support for fuels that "…lead to sustainable feedstocks…"

The AB 118 program can provide, grants, loans, loan guarantees, revolving loans, or other appropriate measures, to public agencies, businesses and projects, public-private partnerships, vehicle and technology consortia, workforce training partnerships and collaboratives, fleet owners, consumers, recreational boaters, and academic institutions to develop and deploy innovative technologies that transform California's fuel and vehicle types to help attain the state's climate change policies.

The legislation is specific about vehicle technologies: "Vehicle technology" means any vehicle, boat, off-road equipment, or locomotive, or component thereof, including its engine, propulsion system, transmission, or construction materials

The Eligible Projects, as described in the AB 118 text, are:

(1) Alternative and renewable fuel projects to develop and improve alternative and renewable low-carbon fuels, including electricity, ethanol, dimethyl ether, renewable diesel, natural gas, hydrogen, and biomethane, among others, and their feedstocks that have high potential for long-term or short-term commercialization, including projects that lead to sustainable feedstocks.

(2) Demonstration and deployment projects that optimize alternative and renewable fuels for existing and developing engine technologies.

(3) Projects to produce alternative and renewable low-carbon fuels in California.

(4) Projects to decrease the overall impact of an alternative and renewable fuel's life-cycle carbon footprint and increase sustainability.

(5) Alternative and renewable fuel infrastructure, fueling stations, and equipment. The preference in paragraph (10) of subdivision (b) shall not apply to these projects.

(6) Projects to develop and improve light-, medium-, and heavy-duty vehicle technologies that provide for better fuel efficiency and lower greenhouse gas emissions, alternative fuel usage and storage, or emission reductions, including propulsion systems, advanced internal combustion engines with a 40 percent or better efficiency level over the current market standard, light-weight materials, energy storage, control systems and system integration, physical measurement and metering systems and software, development of design standards and testing and certification protocols, battery recycling and reuse, engine and fuel optimization electronic and electrified components, hybrid technology, plug-in hybrid technology, fuel cell technology, and conversions of hybrid technology to plug-in technology through the installation of safety certified supplemental battery modules.

(7) Programs and projects that accelerate the commercialization of vehicles and alternative and renewable fuels including buy-down programs through near-market and market-path deployments, advanced technology warranty or replacement insurance, development of market niches, and supply-chain development.

(8) Programs and projects to retrofit medium- and heavy-duty on-road and nonroad vehicle fleets with technologies that create higher fuel efficiencies, including alternative and renewable fuel vehicles and technologies, idle management technology, and aerodynamic retrofits that decrease fuel consumption.

(9) Infrastructure projects that promote alternative and renewable fuel infrastructure development connected with existing fleets, public transit, and existing transportation corridors, including physical measurement or metering equipment and truck stop electrification.

(10) Workforce training programs related to alternative and renewable fuel feedstock production and extraction, renewable fuel production, distribution, transport, and storage, high-performance and low-emission vehicle technology and high tower electronics, automotive computer systems, mass transit fleet conversion, servicing, and maintenance, and other sectors or occupations related to the purposes of this chapter.

(11) Block grants administered by not-for-profit technology consortia for multiple projects, education and program promotion within California, and development of alternative and renewable fuel and vehicle technology centers.Demonstration and deployment projects that optimize alternative and renewable fuels for existing and developing engine technologies.

Additional funding guidance from AB 118 includes:

- Projects to produce alternative and renewable low-carbon fuels in California.
- Projects to decrease the overall impact of an alternative and renewable fuel's life-cycle carbon footprint and increase sustainability.
- Alternative and renewable fuel infrastructure, fueling stations, and equipment. The preference in paragraph (10) of subdivision (b) shall not apply to these projects.
- Projects to develop and improve light-, medium-, and heavy-duty vehicle technologies that provide for better fuel efficiency and lower greenhouse gas emissions, alternative fuel usage and storage, or emission reductions, including propulsion systems, advanced internal combustion engines with a 40 percent or better efficiency level over the current market standard, light-weight materials, energy storage, control systems and system integration, physical measurement and metering systems and software, development of design standards and testing and certification protocols, battery recycling and reuse, engine and fuel optimization electronic and electrified components, hybrid technology, plug-in hybrid technology, fuel cell technology, and conversions of hybrid technology to plug-in technology through the installation of safety certified supplemental battery modules.
- Programs and projects that accelerate the commercialization of vehicles and alternative and renewable fuels including buy-down programs through near-market and market-path deployments, advanced technology warranty or replacement insurance, development of market niches, and supply-chain development.
- Programs and projects to retrofit medium- and heavy-duty on-road and nonroad vehicle fleets with technologies that create higher fuel efficiencies, including alternative and renewable fuel vehicles and technologies, idle management technology, and aerodynamic retrofits that decrease fuel consumption.

- Infrastructure projects that promote alternative and renewable fuel infrastructure development connected with existing fleets, public transit, and existing transportation corridors, including physical measurement or metering equipment and truck stop electrification.
- Workforce training programs related to alternative and renewable fuel feedstock production and extraction, renewable fuel production, distribution, transport, and storage, high-performance and low-emission vehicle technology and high tower electronics, automotive computer systems, mass transit fleet conversion, servicing, and maintenance, and other sectors or occupations related to the purposes of this chapter.
- Block grants administered by not-for-profit technology consortia for multiple projects, education and program promotion within California, and development of alternative and renewable fuel and vehicle technology centers.