The Future of Natural Gas Engines in Heavy Duty Trucks: The Diesel of Tomorrow?
Natural Gas Adoption as a Class 8 Fuel of Choice

Forces For Change

- Total Fuel Cost Per Mile
- Long Term Oil/Diesel Prices
- Price Stability (Pump Price Insensitive to NG Spot Prices)
- Energy Independence
- Recent Major Engine and OEM Vehicle Product Announcements
- 80% ENGINE Part Commonality with Diesel
- No Aftertreatment (No SCR System, No DEF Additive)
- Infrastructure Investments & Announcements (Clean Energy, Trillium, and Shell)
- Sustainability Commitment (& Green Marketing)

Forces Against Change

- Energy Content
- Engine Efficiency
- LNG/CNG Tank Cost
- Range
- Few Product Offerings
- LNG Handling (Cryogenic)
- Training (Drivers, Technicians, Sales, Marketing, Accounting, HR, etc.)
- Major Investment to Bring Repair Facilities Up to Codes
- Little Refueling Infrastructure
- Uncertain Truck Residual Value

Environmental: Extraction (Frac’ing) Concerns: Contamination of Water Table, Earthquake Risk, Escaped Gas*

Environmental: Combustion Advantage: Least CO$_2$ of Fossil Fuels

* The radiative forcing (heat trapping ability) of methane is many times that of CO$_2$. However, CO$_2$ lasts many times longer in the atmosphere.
Throughout history, the primary fuel of choice has changed for passenger cars and trucks. Changes occur because of a host of influencing factors. This paper will examine those influences and suggest the probability of changing fuel usage for heavy duty trucks. Before attempting to predict future changes, it is always beneficial to consider the past and the present to gain a frame of reference for the future. In addition, a little orientation to the basics of natural gas is included.
HYPOTHESIS

A fundamental change may be on the horizon. The North American commercial vehicle truck market will see a measured shift to the use of natural gas as a fuel for heavy duty and class 8 vehicles, displacing currently used diesel fuel. In the next 12 to 15 years, natural gas will become the fuel of choice for about 50% of on-highway vehicles.
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EXECUTIVE SUMMARY

Natural gas, as a source of fuel to power on-road vehicles, was first introduced in 1860. Today, estimates suggest there are about 120,000 natural gas vehicles of all types on U.S. roads. The majority of the units are automobiles with about 13,000 of them heavy vehicles in refuse, transit, dray, and pickup and delivery operations.

ACT believes conditions are now right for natural gas to become a serious contender for powering on-highway heavy duty trucks for general freight hauling. If this is correct, and if key factors maintain their current favorable status, natural gas could power half the Class 8 trucks produced for the U.S. market by 2025.

ACT’s NG report explains the factors that will ultimately determine the success of natural gas displacing diesel as the fuel of choice in large swaths of the commercial vehicle market. Those factors include:

- A sufficient supply of affordable natural gas over the forecast horizon
- Continued development of natural gas engines and related technology, with the subsequent placement of those engines in a broad array of applications
- Recognition that a refueling infrastructure is needed. Planning and investment decisions are being made now
- Cost, cost, cost
- Safety issues, both perceived and potential
- Environmental and health considerations

First and foremost among these factors is the supply of affordable natural gas. The discovery of significant proven and estimated reserves of raw natural gas is the catalyst that put the discussion on the table. Hydraulic fracturing or frac’ing is a drilling technique that has unlocked access to vast deposits of natural gas. Natural gas already plays a significant role in meeting the country’s energy needs in every segment except transportation. Natural gas has displaced coal to become the number two fuel for electrical generation. Further, the overwhelming majority of proposed new power plants will use natural gas to generate electricity. Further, the overwhelming majority of proposed new power plants will use natural gas to generate electricity. These uses of NG will not deplete supply or significantly alter price relationship with diesel.

Natural gas as a fuel for on-road vehicles is currently in its early stages of adoption and we believe it is positioned for similar success in the transportation arena. The transition for transportation will not be fast: It took several decades for commercial vehicle to transition from gasoline to diesel. While the move to natural gas will not be as protracted, it also will not occur overnight. Ultimately, cost will be the catalyst that will dictate the speed and extent of the transition. This is because cost savings will drive the development of technology and the introduction of new engines and vehicles as the market moves through the takeoff stage of the adoption curve. As product proliferation occurs, synergistic gains will result in equipment cost reductions, thereby accelerating the rate of adoption.

As the raw and manufactured products are developed, so too will the infrastructure needed to support them. Already, there is a growing list of options available for refueling and servicing natural gas powered trucks, but the work is far from being complete. Several national natural gas suppliers have announced major initiatives to build refueling stations at strategic points along high density transportation corridors. Proposed construction is progressing, with some stations in place before a sufficient concentration of trucks exists to justify commercial viability.

In the same vein that location, location, location is the mantra of the real estate market, cost, cost, cost is the rallying cry of natural gas proponents. Early adopters of natural gas vehicles are a testament to that position. Consider the refuse market, which has a high concentration of NGVs. Part of the rationale behind their use is that methane, which can be converted into natural gas, is a by-product of refuse sites, so their raw material costs are very low. Another example is the transit bus market, which also has a very high percentage of natural gas powered units. This is a market that has benefitted greatly from subsidies. In both cases, there were sufficient financial enticements to easily sway the conversion decision. Going forward, we believe the favorable payback opportunities that exist will make subsidies unnecessary.

Safety is probably the most emotionally charged facet of the natural gas debate, and rightfully so. The good news is that with proper training and handling, natural gas can be as safe, and perhaps safer, than diesel fueled vehicles. Because it is a
gas, it vents to the atmosphere, unlike diesel and gasoline that pool on the ground. More than 70 million households and business use natural gas every day. If natural gas were unsafe, this would not be the case.

Another theme worthy of consideration is the environmental impact of natural gas. Concerns have been raised about increased earthquake activity, groundwater contamination, and inadvertent venting of Greenhouse Gases (GHG) during the drilling and extraction process. This issue is germane not just to transportation, but for all users of natural gas. Clearly, these allegations deserve earnest research to determine how best to address them. However, they are not likely to be a stumbling block for the adoption of natural gas powered vehicles. As a side note, the venting of methane from LNG powered trucks when not in use has been cited as another area for research.

ACT examined various fleet and owner operators’ perspectives on natural gas powered vehicles for the project, particularly as they relate to adoption of NGVs. This work, along with other analysis, was an important input into the penultimate conclusion of the paper, the penetration assumptions and resulting unit forecasts.

Finally, the paper objectively examines roadblocks and objections to natural gas and attempts to address those concerns. Included are a “Baker’s Dozen,” list of thirteen commonly held misconceptions about natural gas. Topics covered are cost, operational performance considerations, safety, and environmental impacts. In each case, a convincing counter-argument is presented that refutes the myths.

The section also includes questions that survey panelists asked of us, along with appropriate responses. If there is one take-away from this section, it is that there is a significant need for education as it relates to natural gas and its use in commercial vehicles. That education gap ranges from truckers to the many suppliers to the industry and especially the governments regulating it.

The sheer abundance of available natural gas has changed the supply/demand equilibrium to the point that a very solid case can be made for natural gas as a transportation fuel. Combined with its inherently more environmentally friendly attributes, the door is wide open for continued development of natural gas engines, vehicles, refueling infrastructure, and maintenance facilities. Real economic savings and energy independence will be the driving forces as the U.S. Class 8 commercial vehicle market comes to the realization that no other alternative offers the same logical choice as natural gas, THE DIESEL OF TOMORROW.
CHAPTER 1-5
HIGHLIGHTS AND SUMMARIES

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Chapter 1: NATURAL GAS AND THE U.S. ENERGY MARKET

- Prices at the pump for natural gas (DGE: diesel gallon equivalent) are relatively insensitive to changes in natural gas domestic spot prices while diesel prices are very sensitive to changes in the price of a barrel of oil, both domestic and international, because of the cost composition of a gallon of each fuel.
- In 2012, oil is about 7 times as expensive as natural gas (comparable DGE). A major driver of this cost advantage was the introduction of hydraulic fracturing (frac’ing) in domestic shale formations.
- The U.S. has vast natural gas reserves, including Marcellus shale, which has experienced intensive development the past several years.
- The combustion of natural gas relative to diesel and coal is environmentally friendly, but extraction may be environmentally problematic, including concerns with frac’ing and methane venting.
- Natural gas is a major energy source for 3 of 4 U.S. energy usage sectors: industrial, residential, and commercial. The exception is transportation.
- Gas has displaced coal as the second largest source of energy for the United States. Petroleum remains first with nuclear and renewables having single digit percentages. Note: Electricity is a transmission mode for other energy sources.
- The rate of growth of energy consumption in the United States has slowed profoundly since the 1970s, with both energy use per capita and energy per dollar of GDP declining. The drivers include conservation, regulation, and offshoring of industry with a loss of jobs.
- Low cost natural gas will gain market share from other energy sources and exert downward pressure on prices over time.

CONCLUSION: Domestically sourced natural gas will ultimately become the dominant source of energy for the United States to include transportation as the many factors associated with this growth are resolved: technological, geological, environmental, political, geopolitical and economic. Energy independence will become one of the driving forces as well as cost.
Chapter 2: CHANGES IN THE PAST

- The shift of our largest trucks from gasoline to diesel was unexpected. There was no infrastructure for diesel: fueling stations, shops, spare parts, parts distribution, trained technicians, or (initially) major investments by OEMs or support firms. Depending upon how you count, this transition took decades: 1930s to the 1960s/1970s.
- In contrast and despite everyone’s expectation and with substantial investments by the OEMs, there was no shift from diesel to turbine in the 1970s.
- At one time electric automobiles were 30% of the market. They are now less than 1%, but will be much higher in the future as technology meets more clearly defined needs. Electric for line haul trucks presently won’t work, but hope remains eternal.
- During the era of overall vehicle length regulations through 1986, the desire or need for shorter tractors constrained engine and vehicle configuration and design, indirectly leading to cabover tractors. Once the length law was changed to trailer only, class 8 tractor demand quickly shifted to medium and long conventional designs, but not short versions.

CONCLUSION: The lesson of history is that profound changes in the powering of motor vehicles happen, but they are hard to predict and do not occur overnight. These changes are cost driven, only deviating within the constraints of law.
Chapter 3: INTERNAL COMBUSTION ENGINES: THE BASICS

- The challenge of simultaneously engineering engine torque and power, fuel economy, low levels of multiple types of emissions, drivability, and reliability is an exercise in comprise.
- There are two basic types of internal combustion engines in vehicles: spark ignition (used with NG and gasoline) and compression ignition (used with diesel).
- Compression and spark ignition use the 4 stroke Otto cycle: intake, compression, ignition/power, and exhaust.
- One gallon of diesel with 138,645 BTUs of energy has significantly more energy than NG; it takes 135 cubic feet of NG to produce the same energy level. Note that decisions on adopting or not adopting natural gas should not be based on energy cost per unit of volume, but on the cost per mile of hauling freight.
- Over the years, a number of technologies have been used to increase vehicle power including supercharging, turbocharging, and direct injection.
- NOx is produced when nitrogen is exposed to high temperatures in a combustion chamber. EGR is a tool to reduce combustion temperature.
- To achieve all emission requirements simultaneously and have cost effective power output, a number of technologies are used with diesels: Exhaust Gas Recirculation (EGR), Selective Catalytic Reduction (SCR) that employs Diesel Exhaust Fluid (DEF), and costly particulate traps. These are heavy and expensive additions.
- Diesel and natural gas engines have many similarities and share most components.
  - Approximately 80% of the parts are the same.
  - The ECU (Electronic Control Unit) is similar with different programming.
  - Natural gas engines (except Dual Fuel HPDI) are spark ignited.
- Diesel engines are more efficient because they have a higher compression ratio (about 16:1) than natural gas (about 12:1). If natural gas was compressed more than 12:1 it would prematurely ignite.
- There are two basic types of natural gas fuel supplies: Compressed Natural Gas (CNG) and Liquid Natural Gas (LNG).
  - Liquid Natural Gas (LNG) is Compressed Natural Gas (CNG) with an extra step: cryogenic liquefaction which reduces its temperature to minus 260 degrees F, allowing more volume to be hauled in the same space.
  - By the time the CNG and LNG enter the engine, they are in a gaseous state; the engine does not know if the fuel source is CNG or LNG. A spark ignited natural gas engine does not need combustion aftertreatment such as SCR and DEF or a particulate trap to meet emission requirements. However, a 3-way catalyst will be needed, much like an automobile.
  - The weight savings on the spark ignited NG truck versus the equivalent diesel powered truck is approximately 400 pounds when you add the diesel aftertreatment. However, the weight of the CNG or LNG fuel tanks can increase the overall weight of a natural gas powered truck.
- There are several alternatives to getting natural gas to the fueling station:
  - CNG fueling stations can use natural gas from a pipeline to an operation with varying compression, cleaning, etc., capabilities.
  - LCNG is nothing more than CNG taken from LNG and is a fuel option when NG is not available elsewhere.
  - Liquefaction is a large scale industrial process from which LNG is processed from NG to a liquid state at -260 degrees F and subsequently delivered by tanker.
- Fuel storage tanks on trucks are different for natural gas and for diesel:

**CNG tanks:**
- are pressurized up to 3,600 psi. No venting is required for CNG.
- can be specified for vehicles with a variable number of tanks depending on the desired range before refueling. There are four tank types ranging from TYPE 1: heavy all steel units to TYPE 4: light weight units but with high heat retention when refueling.
o are 3.7 times the size of diesel tanks for equal travel distance.

**LNG tanks:**
o are like thermos bottles.
o are slightly pressurized, but vent when natural gas is ‘boiled off’ as it warms and is not needed for immediate use.
o are 1.7 times the size of diesel tanks for equal travel distance.

- CNG and LNG tanks are highly engineered, but if one should be breached, the NG vents to the atmosphere rather than collecting on the ground like diesel and gasoline where it could encounter ignition.
- Fueling LNG requires special handling because of its temperature at minus 260 degrees F to include gloves and face shields.
- Because LNG tanks vent to atmosphere when usage stops after a few days, LNG repair facilities require special safety features to prevent gas accumulation.
- Fast fueling of CNG tanks produces heat which limits the speed of refueling and the volume of fuel that can be added.
- Slow fueling is favored by refuse, municipal, and transit buses that come home every night as it generally costs less to fuel and the tanks have a higher fill rate.
- Refuse sites and some agricultural operations produce methane as a byproduct. After needed processing, this gas can be used to power vehicles just like NG from the pipelines.
- Other alternatives to gasoline, diesel, and natural gas include propane, Liquefied Petroleum Gas (LPG), and hydrogen, hythane, and dual fuel (capable of running on two fuels); dual fuel is particularly popular in military applications.
- Another description of the term dual fuel system is High Pressure Direct Injection (HPDI) which uses 95% natural gas and 5% diesel. The small amount of diesel is injected into a cylinder and compressed. When the diesel ignites in the compression stroke, natural gas is injected from the same injector.
o With higher compression ratios of 16:1, this produces basically the same power, torque, and fuel economy as 100% diesel.
o This system still requires all of the diesel emission add-ons.
- Natural gas emits less greenhouse gases than diesel during combustion because of its chemical composition (twice as many hydrogen atoms per carbon atom—hydrogen is the key to energy release in the combustion of hydrocarbons).
- Fortunately, 2010 certified diesel engines emit a small fraction of the NOx and particulates emitted in prior years and are now very close to 2010 spark ignited NG engines.
- The ultimate curb weight for natural gas trucks will depend upon the number and type of CNG or LNG tanks added. It will be possible to specify the number of tanks to achieve a certain range. Two 60 gallon DGE LNG tanks (120 gallons total) will weigh about 2,200 pounds while five CNG tanks totaling 125 gallons DGE (steel) could weigh about 4,000 pounds if TYPE 1: all steel. For fuel comparison, be sure to deduct the weight of the diesel fuel and tanks.

**CONCLUSION:** Total cost is the driver of technology employed to achieve specified levels of power and emissions. Periodically the factors determining total costs of different strategies and inputs require fundamental review of the technology choice. The decline in the cost of natural gas and new engine/vehicle offerings have brought us to such a point. The industry is at the front end of invention as it learns how to work with NG in the most efficient, productive manner.
CHAPTER 4: THE PRESENT

- Although there are few natural gas product offerings today, there are two game changers in process:
  - Dramatic decline in the cost of natural gas relative to diesel and other fuels with the expectation that NG will continue to be favorably priced long term (barring emissions intervention that alters NG availability).
  - New HD engine and OEM truck offerings that already have been announced to enter the market place in 2013-2015 with more expected to follow.

- Today’s diesel fuel surcharge could be both an opportunity and a detriment. This is an opportunity for increased margins as truckers mix their fleets with both diesel and natural gas powered trucks. The detriment, however, exists because some shippers are already seeing an opportunity for lower fuel surcharges as they expect to share the cost savings with truckers. Natural gas as a stable, domestically produced fuel could ultimately be the catalyst for eliminating the fuel surcharge, a major change waiting in the wings.

- For school, shuttle, and transit buses, the initial motivation for natural gas was a blend of cleaner air and an opportunity to purchase new equipment with large grants from local, state and federal agencies.

- Transit buses, of which an estimated 20% are powered by natural gas, are the leading vocational use today.

- Operators of refuse trucks and urban buses, which are highly visible and have a duty cycle allowing for overnight refueling, were early and large adopters of CNG.

- West coast ports make extensive use of natural gas trucks for pollution reduction.

- The United States has only 0.1 million of the world’s 15 million natural gas vehicles.

- The fact that spark ignited natural gas is quieter than diesel leads some to perceive natural gas as less powerful. One needs to look at the horsepower rating of the vehicle. This is a strong plus for spark ignited NG engines.

- Present natural gas offerings for the truck market are:
  - Cummins Westport 8.9L spark ignited (CNG or LNG)
  - Westport Innovations 15L dual fuel diesel/LNG

- Announced offerings for the heavy duty Class 8 truck market are:
  - Navistar 13 L (2013)
  - Cummins Westport 11.9 (2013-2014)
  - Almost all U.S. truck OEMs now have announced new natural gas offerings with the majority scheduled for introduction in 2013.
  - Navistar and Clean Energy Fuels have a cooperative marketing agreement.

- Clean Energy plans to complete 96 natural gas highway stations between Q2’12 and Q1’13. There are other companies that are also in the process of adding NG fueling locations, both CNG and LNG. The initial concentrations are supporting high density national and regional freight corridors.

- The primary question facing those considering the adoption of natural gas is, “How long will the favorable price differential with diesel last?” See chapter one for a complete discussion of the viability of NG as a long-term fuel for the nation for all energy needs. The forecast is that NG will remain favorably priced relative to diesel into the foreseeable future and beyond. The biggest unknown remains potential environmental issues dealing with methane gas release.

- No pending legislation or rules are currently on the books that will negatively impact the adoption of natural gas by transportation. Natural gas meets EPA emission requirements today without aftertreatment except for adding a 3-way catalyst and EGR.

CONCLUSION: A number of factors favorable to a substantial adoption of natural gas propulsion in commercial trucks are in place.
CHAPTER 5: FACTORS IMPACTING CHANGE

- Establishing fueling stations in the major national and regional truck transportation lanes is absolutely key to expanding natural gas fuel usage beyond those vehicles that return home every night.
- The fact that today’s vehicle technicians use laptop computers to diagnose problems and facilitate repairs will simplify the transition from diesel to natural gas.
- The analysis of natural gas engines in commercial trucks can be divided into two groups: those written before and those written after the March 2012 Mid-America Trucking Show. At this show, there were numerous major announcements about new heavy duty natural gas engines, new fueling station plans and commitments as well as new OEM natural gas fueled truck offerings.
- Among the fuels which have been mentioned for commercial vehicles are Diesel #2, B10 Biodiesel, B100 Biodiesel, Gasoline, Gasoline + 10% Ethanol, LPG (Propane), Flex-fuel (Ethanol E85), LNG, and Methanol (M100).
- Among the main questions in considering alternatives to diesel are technical merits, emissions, fuel distribution systems, and cost per DGE.
- New 12, 13, and 15 liter engines will be released in the next two to three years.
- Choices among fuels, like choices in engine design and engineering to achieve multiple objectives, are exercises in the science of compromise.
- The determinants of fuel selection include the following: overall fuel economy, long term fuel availability, fuel costs, emission characteristics, engine reliability and durability, national and world politics, national security and more.
- Only about 1/3 of the energy of an internal combustion engine propels the vehicle. One third is lost by the radiator and another 1/3 in exhaust.
- The Fisher-Tropsch process transforms gas (in a gaseous state, including the product of coal gasification) to a liquid fuel.
- Dimethyl Ether (DME) is the product of converting natural gas into methane, using catalysts, converting the methane into DME, which is a clean compression ignited fuel.
- Among the advantages of natural gas for the U.S. are:
  - The country has a 100-year supply of natural gas which does not involve importation.
  - Natural gas burns cleanly.
  - Natural gas engines are quieter than diesel engines.
  - Limitations and risks associated with CNG and LNG are understood.
  - To some degree, natural gas is a renewable resource, providing a use for methane produced by refuse sites and other locations.
- There are concerns about natural gas extraction because frac’ing infuses chemicals into the groundwater, results in chemical waste which must be recycled, releases methane (a greenhouse gas) into the atmosphere, and might cause earthquakes.
- Natural gas vehicles have commanded a premium because they were aimed at niche markets.
- The niche marketing of natural gas resulted in the vehicles having characteristics which might be disadvantageous in a wider market, including horsepower and transmission choice.
- 40% of refuse trucks use natural gas.
- There have been very generous government incentive programs for natural gas vehicles. Although these have ended, similar programs would certainly promote adoption of natural gas if they are enacted in the future.
- More thought needs to be given to disposition of natural gas commercial vehicles as used vehicles. Assuming NG vehicles are adopted as believed, there will be a secondary market for those truckers that cannot afford new, but need the low cost of operation to compete or want a lower cost of entry to try the new technology. Export markets are another avenue for sale as NG usage is global.
- Service facilities for natural gas will have to comply with safety requirements, such as NFPA 30A.
- Under reasonable assumptions, a natural gas vehicle can have fuel savings of about $20,000 per year driving 100,000 miles over a five year trade cycle with a 6 mpg diesel fuel economy, assuming $1.00 fuel savings for 20,000 DGE per year with a vehicle up-charge of $20-$50K.
Much of the low hanging, total fuel cost fruit of diesel has been achieved already. Thus, if early adopters of natural gas are successful in achieving substantial cost savings, their competitors will have little alternative to regain a competitive advantage.

The technology of natural gas vehicles is likely to improve as more vehicles are purchased while it is expected the up-charge for NG vehicles will decline due to increased volume of tanks and associated installation parts.

As with the adoption of any new technology, there will be hiccups along the way for the supply chain, quality concerns for unique parts, service center availability along with qualified technicians, etc.

The advantages of CNG over LNG are: fuel cost, handling, safety (handling and venting), and no loss of fuel when parked (venting).

The advantages of LNG over CNG are: weight, possibly vehicle cost, use where there is no pipeline access, and fuel density/range.

**CONCLUSION:** The share of natural gas vehicles will grow because of cost and environmental advantages over diesel. Natural gas is a domestic resource that could ultimately supply 100% of transportation’s fuel needs. The transition from diesel will be relatively easy and the same can be said for dual fuel gasoline/NG. The adoption of natural gas will be faster than the transition from gasoline to diesel in commercial trucks. It is no longer a question of using NG, but exactly when, where, and how much.
Chapter 1: NATURAL GAS AND THE U.S. ENERGY MARKET

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INTRODUCTION

The new buzz in energy markets is natural gas and the opportunities it presents for lowering the cost of energy, changing the pattern of usage of energy sources, boosting innovation, and improving the competitive posture of the U.S. economy.

The public’s interest in natural gas as a fuel has increased greatly in recent years, propelled, to a large extent, by the dramatic drop in natural gas prices relative to other sources of energy. The introduction of new technology, including hydraulic fracturing (frac’ing), has made the natural gas derived from shale more easily and readily available. The supply has increased and, consequently, the price has declined. Although current price levels have triggered a pull back in exploration, we believe that the favorable natural gas price nexus will remain in place even as demand for natural gas increases and demand for other forms of energy drops due to intensified competition.

Another advantage of natural gas is its smaller negative effect on the environment. Of all petroleum based fuels, it has the lowest carbon content per unit of energy and very few non-carbon related emissions. There are some concerns that the new drilling techniques being used might pollute the drinking water or cause natural disasters like earthquakes. Barring some large scale disaster like the Three Mile Island nuclear plant leak or Japan’s tsunami, it is highly unlikely that new regulations will be imposed that will severely restrict natural gas exploration and drilling. But the political reality of concerns must be understood and addressed to avoid unneeded restrictions on drilling and exploration.

Transportation, utilities and petrochemicals are the sectors most likely to increase their usage of natural gas as a source of energy, as long as it makes economic sense. Currently, transportation uses almost no natural gas while utility usage of natural gas represents only 18% of this sector’s energy demand. Coal is the major energy source for the utilities industry, accounting for almost half the energy input.

The focus of this paper is the long-term viability of natural gas as a transportation fuel. To be sure, there are many challenges to successful expansion of natural gas usage in transportation. These include such issues as expanding a widespread distribution network, further development of new vehicle technologies, roll-out of engine families beyond current niches, and appropriately addressing safety and environmental concerns. Providers of competing energy sources will ultimately react through the political or economic sectors to reduce the price advantage of natural gas. It is our contention that natural gas will maintain its relative cost advantage which, in turn, will lead to an increased role as a source of energy in the U.S. economy.
ENERGY USE OVER TIME

The U.S. economy has been a strong consumer of energy for most of the 20th century and remains so in the 21st century. Chart 1 depicts the usage of energy in the U.S. over the past sixty years. In 1955, approximately 40 quadrillion BTU equivalents of energy were consumed. By 1973, the figure had almost doubled to nearly 76 quadrillion BTUs, an average annual growth rate of 3.6%. Growth slowed dramatically from 1973 to 2010, with a 0.8% average annual growth rate, as the cost of energy increased several fold. The higher costs were driven by the sharp increase in petroleum prices that resulted from the oil shocks of the 1970s. The imposition of government regulations such as the national maximum speed law and higher fuel economy standards on vehicles aimed at offsetting the negative environmental impacts of energy, particularly carbon emissions of fossil fuels, also contributed to a slowdown in energy use. This deceleration in energy use has continued. During the first decade of the 21st century, total consumption of energy remained virtually unchanged, even as the U.S. population rose by 26 million or 9.3%, and economic activity as measured by real GDP increased by $1.9 trillion or 16.8%.

The current U.S. Energy Information Administration forecast calls for total primary energy usage to grow from 98 quadrillion BTUs in 2010 to 107 quadrillion BTUs in 2035, resulting in a 1973 to 2035 average annual growth rate of 0.6%.

PER CAPITA ENERGY USE

Population growth and income are the primary drivers of energy demand. Chart 2 shows the change in per capita energy usage while Chart 3 shows the amount of energy used per dollar of real GDP. Energy usage per capita rose steadily from WWII to 1973. It declined in response to the energy shocks of the 1970s. Despite the ubiquitousness of portable personal electronic devices, from the late 1980s until the Great Recession, per capita consumption remained relatively flat and then declined a bit in the wake of the Great Recession of 2007-2009. Again, government and manufacturer driven energy efficiency, rather than consumer demand, led to many of the improvements. In 2010, per capita energy use was approximately 317 million BTUs, about where it was at the end of the 1970s.

ENERGY PER GDP DOLLAR

Energy per dollar of GDP has been in steady decline since the first Arab oil embargo in 1973. The sharp uptick in oil prices triggered the implementation of efficiency improvements in the economy as well as the off-shoring of energy intensive industries. The steady movement of heavy industry from U.S. jurisdiction and its replacement with higher value, lower energy
intensive activity, represents a structural change in the U.S. economy, and also has contributed to reduced energy use. By 2010, a dollar of real GDP was associated with just 7.4 thousand BTUs of energy. This is almost half the energy used per GDP in 1975. Over that time, real GDP grew approximately two and a half times. From an energy perspective, the U.S. economy is now nearly five times more efficient.

THE ENERGY COMPLEX: AN OVERVIEW

Energy users can be divided into four categories:

- Industrial (manufacturing)
- Transportation (all modes)
- Residential (heating/cooling, lighting, etc.)
- Commercial (business and retail)

Chart 4 depicts the change in energy usage from 1990 to 2010. The largest user of energy is the industrial sector. In 2010, this sector accounted for 31% of the energy used in the U.S. (30.1 quadrillion BTUs) which represented a drop of seven percentage points from the 38% level achieved in 1990. The shift in industrial structure, mainly the movement of manufacturing overseas, was largely responsible for the decline in usage. Transportation, the second largest user of energy, accounted for 28% of energy usage in 2010 (27.5 quadrillion BTUs), residential energy totaled 23% (22.2 quadrillion BTUs), and commercial usage totaled 18% (18.2 quadrillion BTUs). All three segments increased their market share by one to three percentage points from 1990.

ENERGY SOURCES

There are five major sources of energy in the U.S. economy. They are petroleum, natural gas, coal, nuclear, and renewables. Renewables include sources such as wind, solar, and bio-degradable matter. Electric power is not an independent source of energy, but rather a mode of transformation from one form of energy to another.

Chart 5 shows the changing importance of the several energy sources over the past twenty years. Petroleum is and has been the leading source of energy, providing 37% of the U.S. economy’s energy usage (36.0 quadrillion BTUs). This is a bit less than its position in 1990 when it accounted for 40% of total energy. Natural gas is the second largest source of energy, accounting for 25% of the economy’s needs (24.6 quadrillion BTUs) as compared to 23% of the total in 1990. Coal, which has recently fallen to third position, provides about 21% of total energy utilized (20.8 quadrillion BTUs) or a bit less than in 1990. Nuclear energy provides an additional 9% of the energy needs (8.4 quadrillion BTUs) slightly more than its 1990 contribution. The remaining power is provided by renewables (8.0 quadrillion BTUs).

ENERGY USES BY SOURCE

The relationship between energy source and sector of usage is shown in Chart 6 and Table 1.1. Petroleum is the leading source of energy, providing 37% of the U.S. economy’s energy with about 70% (diesel, gasoline, etc.) destined to the transportation sector and an additional 22% going to the industrial sector. Natural gas is the second largest source of energy accounting for 25% of the economy’s needs with its output about evenly divided between the industrial, residential and commercial and electric generating sectors. Only a minuscule amount, 3%, is used by the transportation sector. Coal, the third energy sector, provides about 21% of energy’s share with 92%
directed toward the electric generating sector. Nuclear energy provides an additional 9% of the energy needs with all of it going into electricity. Renewables represent the remaining 8% with half directed toward electric power and another 28% to industrials.

Viewed from the user’s (demand) perspective, we see that transportation receives almost all its energy from petroleum. In 2010, petroleum represented 93.2% of the power used in the transportation sector. Renewables, which were virtually unknown in 1990, now account for 4.0% of energy source. At 2.5%, natural gas had a smaller slice of the pie in 2010 than it did in 1990, despite growing on an absolute basis. The industrial sector’s energy is supplied primarily by petroleum (26.6%) and natural gas (26.9%) with coal’s role down by nearly 40%, to 5.7%, of 1990s level. Renewables provide an additional 7.5% of this sector’s demand. The industrial sector’s demand for energy has been declining as manufacturing activity has shifted to overseas locations. The residential & commercial sectors get 87.1% of their combined energy from natural gas and electricity, with an additional 12.6% coming from petroleum. Both the residential and commercial use of energy derived from electricity has increased over the past 20 years. We suspect that this is primarily the result of the proliferation of electronic equipment such as computers, instant-on TVs and other income sensitive and technologically new gadgets.

From Chart 6 below, we see that electric power (a means of energy transmission, not an energy source) gets about half its energy from coal, with an additional 21% from nuclear energy and 19% from natural gas.

Note: Data in Table 1.1 on the next page, which treats electricity as an energy source, do not tie to data in Chart 6, which treats electricity as a means of energy transmission,

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**Chart 6 - Primary Energy Flow by Source and Sector - 2010**

### Table 1.1 – Energy Usage by Sector and Source

<table>
<thead>
<tr>
<th>Sector</th>
<th>Petrol</th>
<th>Renew</th>
<th>Nat Gas</th>
<th>Electric Loss</th>
<th>Electric Sales</th>
<th>Coal</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1990</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Industrial</td>
<td>25.9</td>
<td>5.4</td>
<td>26.6</td>
<td>23.3</td>
<td>10.1</td>
<td>8.7</td>
<td>100.0</td>
</tr>
<tr>
<td>Transport</td>
<td>96.5</td>
<td>0.3</td>
<td>3.0</td>
<td>0.2</td>
<td>0.1</td>
<td>0.0</td>
<td>100.0</td>
</tr>
<tr>
<td>Residential</td>
<td>8.2</td>
<td>3.8</td>
<td>26.5</td>
<td>42.7</td>
<td>18.6</td>
<td>0.2</td>
<td>100.0</td>
</tr>
<tr>
<td>Commercial</td>
<td>7.4</td>
<td>0.7</td>
<td>20.1</td>
<td>49.3</td>
<td>21.5</td>
<td>0.9</td>
<td>100.0</td>
</tr>
<tr>
<td>2010</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Industrial</td>
<td>26.6</td>
<td>7.5</td>
<td>26.9</td>
<td>22.8</td>
<td>10.9</td>
<td>5.3</td>
<td>100.0</td>
</tr>
<tr>
<td>Transport</td>
<td>93.2</td>
<td>4.0</td>
<td>2.5</td>
<td>0.2</td>
<td>0.1</td>
<td>0.0</td>
<td>100.0</td>
</tr>
<tr>
<td>Residential</td>
<td>5.5</td>
<td>2.5</td>
<td>22.8</td>
<td>46.8</td>
<td>22.3</td>
<td>0.0</td>
<td>100.0</td>
</tr>
<tr>
<td>Commercial</td>
<td>3.9</td>
<td>0.7</td>
<td>18.0</td>
<td>52.2</td>
<td>24.9</td>
<td>0.3</td>
<td>100.0</td>
</tr>
</tbody>
</table>

### KEY ENERGY SOURCE AND USAGE OBSERVATIONS

Thus far, this survey leads to three significant observations with regard to the current state of energy in the U.S.:

1. **Viewed from the supplier's perspective, natural gas plays an important role in all sectors of the economy, with the notable exception of transportation. If the reasons for the absence of natural gas from transportation can be overcome, then a new source of demand and dynamics is likely to develop.** Additionally, continued competitiveness in natural gas prices will have a major impact on the total economy and not just one segment as is the case with the other elements of energy.

2. **Given the natural gas supply, particularly for the industrial sector, the price of natural gas can have an important impact on the competitiveness of U.S. manufacturing, especially if lower natural gas prices mainly benefit firms located within the geographic boundaries of the U.S.**

3. **In a competitive market, all forms of energy should have similar prices after adjusting for differentials of attributes. Thus, lower natural gas prices should place downward pressure on the other forms of energy.**
HISTORY OF NATURAL GAS PRICES

Various sources of energy are measured differently. Petroleum is measured in gallons, electricity in kilowatt hours, and natural gas is measured in cubic feet. This requires comparisons of various forms of energy to be placed on an equal footing. We do this by first converting units of energy into British Thermal Units (BTUs). Since many of us are familiar with energy in terms of gallons, we will convert everything into diesel gallon equivalents, in units that consist of 139,000 BTUs. Discussions framed in terms of gallons rather than some other unit of measure may also be more comfortable and intuitive. Table 1.2 below lists selected energy sources, standard units of measure (UOM), conversion into millions of BTUs per UOM, diesel gallon equivalents (DGE), current price, and current price on a DGE basis. Lastly, it is critical to understand that just as crude oil is the main raw material and just one cost input into diesel fuel, the same is true for natural gas as a vehicle fuel. Note that crude represents approximately 57% of the cost of a gallon of diesel at the pump ($2.27/$3.98), while natural gas is a much smaller percentage as an input cost, about 15% ($0.34/$2.32) of the pump price of natural gas. Extraction, processing, distribution, storage, and a little profit make up the difference between the cost of the raw fuel price and the pump price for both diesel and natural gas.

An illustration of the impact of changes in input materials underscores the importance of this difference. Suppose natural gas prices double from their current level of about $2.50 per Mcf (cubic feet) to $5.00 per Mcf. The pump price of natural gas vehicle fuel would increase by $0.34, from $2.32 to $2.66. If natural gas prices quadrupled, from $2.50 to $10.00, the pump price would rise to $3.68. With the current diesel pump price, natural gas would have to more than quadruple before it begins to approach diesel’s current price of almost $4.00 per gallon.

BTU = British Thermal Unit
DGE = Diesel Gallon Equivalent = 139,000 BTU
UOM = Unit of Measure
MMBtu = Millions BTUs

Chart 7 presents the prices of these energy sources in terms of diesel gallon equivalents.

- 2012: In May 2012, a gallon of diesel cost almost $4.00. Coal and natural gas, on a diesel gallon basis, would both cost approximately $0.30.
- 2004: A gallon of diesel cost about $1.80 while natural gas cost $0.86 and coal $0.19.

The price of natural gas has dropped significantly over the past seven years (the 2008 spike notwithstanding), increasing significantly its competitive position vis-à-vis other energy forms. A ranking of sources indicates that the most expensive energy is fossil-based diesel, followed by natural gas. Coal is the least expensive. Another noteworthy item is that diesel prices have been increasing faster than the other energy prices in recent years.

<table>
<thead>
<tr>
<th>Table 1.2 – BTU Content of Select Energy Sources</th>
<th>Sources: EIA, U.S. DOE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy Source</td>
<td>Standard UOM</td>
</tr>
<tr>
<td>Crude Oil</td>
<td>Barrel (42 gallons)</td>
</tr>
<tr>
<td>Diesel (Pump Price)</td>
<td>Gallon</td>
</tr>
<tr>
<td>Natural Gas</td>
<td>1,000 cubic feet (Mcf)</td>
</tr>
<tr>
<td>Natural Gas (Pump Price)</td>
<td></td>
</tr>
</tbody>
</table>
Another way of examining the behavior of prices is to look at the differential between various energy prices and diesel. As is clear in Chart 8 below, natural gas prices were roughly one dollar less expensive than diesel from 1994 to 2005. During this period, natural gas consumption, in total and among the various sectors, did not change much. One could infer that a discount of $1 or less for natural gas did not provide sufficient incentive to shift energy sources. The lower price did not adequately compensate for factors such as limited distribution of natural gas, safety or environmental considerations, the necessity to adapt vehicles and engines to use natural gas, or infrastructure needed.

After 2005, the spread between diesel and natural gas measured on an equivalent basis widened dramatically to approximately $2.00 per gallon by 2007 and $3.50 per gallon in 2011. The economics behind this development is that the supply of natural gas increased more rapidly than demand, resulting in a drop in prices. Several supply and demand factors were responsible for the drop in price. The introduction of new technologies, such as horizontal drilling and hydraulic fracturing (frac’ing), reduced the cost of drilling for gas in shale and made previously inaccessible formations reachable. The increase in oil prices, from the $40 to $60 per barrel range in 2004-2005 to over $100 dollars by 2010, provided an incentive to explore and drill for oil as well as revisit previously unprofitable fields. There are geological formations that contain crude oil as well as natural gas. Drilling in these locations is occurring and increasing the stores of oil and natural gas.

In addition to these supply-enhancing actions, the general demand for energy did not grow much. The steep economic downturn from 2007 to 2009 and feeble recovery in subsequent years has kept demand low. High prices and the continual introduction of energy efficiencies, both in industry and households, also acted to reduce demand. Finally, the milder-than-usual weather of the winter of 2011-2012 also contributed to lower demand, especially in the residential and commercial sectors.

Inventories have played a role in this drama. In the second half of 2011, natural gas inventories were, on average, almost 30% higher than normal. The normal level of gas inventories is usually measured as a five year moving average. This excess supply also worked to depress natural gas prices as owners intensified efforts to sell some of this inventory. The net effect of the surplus in supply and sluggish demand was a steep drop in natural gas prices to the $2 per 1,000 cubic feet (Mcf) range.
LONG-TERM ENERGY OUTLOOK

The critical question for long-term planning is whether the current comparative price advantage of natural gas will remain intact or if it will revert back to levels more in line with those experienced from 1994 to 2004. Today’s price of $2.80 Mcf reflects this trend. Some of the factors to consider:

- the break-even level that the new technology has created,
- the rate of production and availability of reserves,
- the pace of supply and demand response to price differentials, and
- the potential for regulatory and environmental restraints on output.

Based on drilling cost estimates, the futures markets and U.S. Energy Information Administration (EIA) projections, natural gas is likely to fluctuate $4.50 to $6.00 per Mcf for the next several years. With crude oil trading at $90 a barrel, this would imply an oil/gas ratio of approximately 17. From 1994 to 2005, this ratio averaged 8 with little fluctuation. From 2007 to 2011, the average was 16, and in 2011 the ratio average was 24. The higher the ratio, the cheaper natural gas price is relative to crude oil. If accurate, these figures suggest that natural gas will remain relatively price-competitive and continue to be an attractive energy source.

Estimates in the paragraph above were based on Table 1.3 below. The table shows annual figures for West Texas Intermediate (WTI) crude prices (per barrel), the natural gas price (per 1,000 cubic feet), and the ratio of WTI/gas for each year.

Assuming that the equilibrium price of natural gas is $5.50 and that the crude oil price is $90, which seems close to the consensus forecast for 2012 and 2013, the ratio would be almost 17 (90/5.50).

Comparing this to the historical record, the average ratio for 1994 to 2004 averages almost 8 (24.3/3.30), meaning that natural gas at a 17 ratio is considerably less expensive relative to crude than it was from 1994 to 2004.

In 2011, the ratio stood at 24. Thus, our projected ratio of 17 suggests that relative to crude, natural gas would be a bit more expensive than in 2011. This is no surprise, as almost everyone in the energy field assumes that the current price of $2.00 to $2.50 is too low and not sustainable.

### Table 1.3 - Relationship of Crude to Natural Gas Prices
(Source: EIA)

<table>
<thead>
<tr>
<th>YEAR</th>
<th>WTI Price/BBL</th>
<th>Natural Gas Price/Mcf</th>
<th>WTI/GAS Ratio</th>
<th>WTI Price</th>
<th>Natural Gas Price</th>
<th>WTI/GAS Ratio</th>
<th>DGE Adjusted</th>
</tr>
</thead>
<tbody>
<tr>
<td>1994</td>
<td>$17.20</td>
<td>$1.95</td>
<td>8.8</td>
<td>$0.41</td>
<td>$0.26</td>
<td>1.6</td>
<td></td>
</tr>
<tr>
<td>1995</td>
<td>$18.43</td>
<td>$1.69</td>
<td>10.9</td>
<td>$0.44</td>
<td>$0.23</td>
<td>1.9</td>
<td></td>
</tr>
<tr>
<td>1996</td>
<td>$22.12</td>
<td>$2.51</td>
<td>8.8</td>
<td>$0.53</td>
<td>$0.34</td>
<td>1.6</td>
<td></td>
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<tr>
<td>1997</td>
<td>$20.61</td>
<td>$2.49</td>
<td>8.3</td>
<td>$0.49</td>
<td>$0.34</td>
<td>1.5</td>
<td></td>
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<tr>
<td>1998</td>
<td>$14.42</td>
<td>$2.09</td>
<td>6.9</td>
<td>$0.35</td>
<td>$0.28</td>
<td>1.2</td>
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<tr>
<td>1999</td>
<td>$19.34</td>
<td>$2.27</td>
<td>8.5</td>
<td>$0.46</td>
<td>$0.31</td>
<td>1.5</td>
<td></td>
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<tr>
<td>2000</td>
<td>$30.38</td>
<td>$4.31</td>
<td>7.0</td>
<td>$0.73</td>
<td>$0.58</td>
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<td></td>
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<tr>
<td>2001</td>
<td>$25.98</td>
<td>$3.96</td>
<td>6.6</td>
<td>$0.62</td>
<td>$0.54</td>
<td>1.2</td>
<td></td>
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<tr>
<td>2002</td>
<td>$26.18</td>
<td>$3.38</td>
<td>7.8</td>
<td>$0.63</td>
<td>$0.46</td>
<td>1.4</td>
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<tr>
<td>2003</td>
<td>$31.08</td>
<td>$5.47</td>
<td>5.7</td>
<td>$0.74</td>
<td>$0.74</td>
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<tr>
<td>2004</td>
<td>$41.51</td>
<td>$5.89</td>
<td>7.0</td>
<td>$0.99</td>
<td>$0.80</td>
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<tr>
<td>2005</td>
<td>$56.64</td>
<td>$8.69</td>
<td>6.5</td>
<td>$1.36</td>
<td>$1.17</td>
<td>1.2</td>
<td></td>
</tr>
<tr>
<td>2006</td>
<td>$66.05</td>
<td>$6.73</td>
<td>9.8</td>
<td>$1.58</td>
<td>$0.91</td>
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<tr>
<td>2007</td>
<td>$72.34</td>
<td>$6.97</td>
<td>10.4</td>
<td>$1.73</td>
<td>$0.94</td>
<td>1.8</td>
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<tr>
<td>2008</td>
<td>$99.67</td>
<td>$8.86</td>
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<td>$2.39</td>
<td>$1.20</td>
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<tr>
<td>2009</td>
<td>$61.95</td>
<td>$3.94</td>
<td>15.7</td>
<td>$1.48</td>
<td>$0.53</td>
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<td>2010</td>
<td>$79.48</td>
<td>$4.37</td>
<td>18.2</td>
<td>$1.90</td>
<td>$0.59</td>
<td>3.2</td>
<td></td>
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<td>2011</td>
<td>$94.88</td>
<td>$4.00</td>
<td>23.7</td>
<td>$2.27</td>
<td>$0.54</td>
<td>4.2</td>
<td></td>
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<tr>
<td>2012</td>
<td>$94.72</td>
<td>$2.32</td>
<td>40.8</td>
<td>$2.27</td>
<td>$0.31</td>
<td>7.2</td>
<td></td>
</tr>
</tbody>
</table>
From 2006 to 2011, the ratio averaged around 14 (79/5.90), thus the ratio of 17 would indicate that natural gas will be a bit cheaper than crude based on the historical experience of the past eight years.

In reality, a good case can be made for crude prices to be closer to the $75 to $80 range. If indeed this were to occur, then the ratio would be closer to the 13 to 14 range, more in line with the price experience of 2007 to 2011.

However, several things could go wrong with this prognostication resulting in a high and/or rising price of natural gas relative to alternative energy prices. One key assumption is that natural gas production will continue to advance, especially for shale-based product. Over the past five years, natural gas production has risen at a 4.5% average annual rate with a surge to 8% in 2011. A slowdown in the rate of production, especially in an environment of rising demand, would put upward pressure on prices and possibly even create supply bottlenecks, but natural gas would continue to be the “price” fuel of choice without question.

It appears that the new drilling technologies have reduced the break-even cost of exploration and drilling to the $5 to $6 per Mcf range, or lower according to others. A recent Businessweek article by Matthew Phillips cited break-even costs as low as $3 to $4, depending on the well, because different wells have different cost structures. In fact, he went on to say that newer, higher producing wells can even be profitable at $2.

Coupled with high natural gas prices, this has been a major driver of activity over the past decade and the reason for the rising supply. Were this assumption of costs to prove overly optimistic, a slowdown and even reduction in production would follow. Measuring such a development is a bit tricky. Wells currently in operation could continue producing, as long as their marginal costs are covered, but new projects and explorations would not occur until prices climbed above the true break-even point or new drilling technology or techniques were introduced. With natural gas prices well below the break-even point today, drilling activity has fallen sharply in recent months. We cannot forget that land lease options force some drilling to keep such options viable.

One indication that current price levels of natural gas are not profitable is the rig count. The rig count is a measure of the number of a rigs actively drilling for oil and gas. Chart 9 below shows the movement of natural gas rigs relative to the price of natural gas from 1994 to today. The number of gas rigs rose in line with movement of natural gas prices from 2003 to 2008. Activity dropped sharply in the wake of the recession when prices dropped. Recently, in the context of historically low gas prices, the rig count has dropped to levels not seen since 1999. While we know that current prices may be an aberration, it will be a while before market forces can determine what the correct price is.
The situation in the crude oil market is a bit different. There, the price of crude has been rising and as a consequence, the rig count continues to advance as high oil prices have made old wells and non-traditional oil sources viable. Chart 10 shows the behavior of rigs and crude prices from 1994 to today.

There are those who argue that estimates of available natural gas...
reserves are grossly exaggerated. For example, the EIA, in its preliminary 2012 Energy Outlook, estimates that unproved technically recoverable shale gas reserves (TRR) total 482 trillion cubic feet. This is almost half of the 827 trillion cubic feet that the agency estimated last year. Most of the decline is the result of a downward estimate of the Marcellus shale formation (see map, prior page). For perspective, the shale gas TRR estimate in 2004 was 83 trillion cubic feet. Given the newness of the technology, lack of experience with the geological formations, and the difficulty of peering into the distant future, a certain amount of uncertainty is to be expected. People have been predicting a peak in oil production almost continuously since the 1960s. While reliable figures seem elusive, it appears likely that whatever the final estimate about recoverable reserves is, it should be enough to maintain a strong pace of production. Chart 11 on the previous page shows the shale gas potential in the U.S. It is also important to keep in mind that recoverability is ultimately a function of price. As the price declines, so does the absolute level of profitable recovery.

Despite some concerns, we feel relatively confident that natural gas prices will remain competitive compared to past periods. If we are correct, then the following are likely to occur:

- substitution of natural gas for other sources of energy will accelerate,
- the price of all energy resources will decline, at least in relative terms,
- increased changes in infrastructure will occur as natural gas becomes more ubiquitous, and
- quite possibly, a round of additional technological change will be initiated throughout the energy sector, not just in natural gas.

Even if natural gas were unable to realize the benefits above, the environmental and health advantages of increased adoption of natural gas would remain significant.
ENVIRONMENT AND REGULATION

With regard to the environment, natural gas has several advantages. Among fossil fuels, natural gas has the lowest carbon content per unit of energy. A comparison to diesel is shown in the graphic below. Diesel consists of 14 carbon atoms and 30 hydrogen atoms, with nearly a 2-to-1 ratio. Natural gas is comprised of one atom of carbon and four atoms of hydrogen, at a 4-to-1 ratio. What’s more, it has few non-carbon emissions. However, there are those who have expressed concerns about methane, a chief component of natural gas. The potential for the leaking of methane in the process of production and transmission may result in Greenhouse Gas (GHG) emissions that could adversely affect the global warming trend.

Of greater concern is the process of accessing the shale gas. In the current procedure, sand, water and chemicals are forced into a well under intense pressure. This creates cracks or fissures in the rock formation and allows the gas and sometimes oil to be released and extracted. The waste water is then pumped back to the surface where it is stored and sometimes processed. The environmental concerns are threefold. First, that high pressure pumping may affect the geological formations and possibly lead to tremors and/or earthquakes. Second, there is concern that the chemicals may leach into and pollute underground water sources. Finally, there is the issue of wastewater disposal. Interestingly, many forget that frac’ing is also used as a means of extracting oil from shale formations. Hence, the same concerns apply.

Some political entities have already reacted to these potential problems. For example, France and Bulgaria have banned onshore exploration. Clearly, imposition of regulations would increase the cost of producing natural gas and thus reduce its current price advantage. Barring some large scale disaster, it is highly unlikely that regulations which will severely restrict the exploration and drilling for natural gas will be imposed.
CONCLUSIONS

- Natural gas as an energy source has been found to be plentiful. The estimated available and accessible reserves should be able to accommodate the strong projected demand.

- Because it is abundant, it is comparatively much lower in cost than other energy sources. Natural gas is likely to remain competitively priced relative to the other energy sources into the foreseeable future. The lower price of natural gas is largely due to the introduction of hydraulic fracturing rather than a temporary over-supply.

- Natural gas’ price advantage is likely to result in a shift away from other sources of energy, petroleum in particular. It should also constrain the ability of competing energy producers to raise their prices. The sectors most likely to benefit from this more competitive market will be transportation, utilities, and the petrochemical industry.

- Natural gas is the cleanest of the available energy sources. With regard to the environment, natural gas has a lower carbon footprint and is a cleaner fuel than others, especially in transportation.

- Globally, natural gas is being located in greater abundance, a factor that will enable environmental demand issues to be addressed while supporting competitive pricing.
Chapter 2: CHANGES IN THE PAST

Turbines to Replace Diesel Power ................................................................. 16-17
Gasoline to Diesel for Trucks ................................................................. 18-19
ACT's hypothesis states change will take place in the use of fuels for commercial vehicles. As we think about the potential change and the reasons for it, it will be helpful to think about changes in the past that did and did not occur with respect to fuel usage to gain some insight. First, we need to review how the diesel fueled engine came into prominence over gasoline fueled and, second, why turbines for on-highway trucks never came to fruition. Let’s examine the latter first.

TURBINES TO REPLACE DIESEL POWER

As WWII ended, the transition to turbine and jet power for aircraft had begun. With the lessons learned about the complexity of high horsepower piston powered aircraft power plants in WWII and the rapidly expanding base of knowledge with the Korean Conflict along with the rapid development of commercial aviation in the late 1940s and early 1950s, it seemed to be a natural progression to adapt turbine power to on-highway trucks.

With the rapid expansion of the new interstate highway system, truck operators wanted more power to haul heavier loads at cruise speeds and have plenty of power in reserve for climbing hills and mountains. The solution to the problem of more power might seem obvious: build current diesel engines with more power. The old hot rod axiom of “the only substitute for cubic inches is more cubic inches” could be implemented. The solution seemed so simple. Build diesel engines with greater displacements and generate more power. Problem solved!

Unfortunately, the solution wasn’t that simple. By law at that time, a typical line haul tractor was limited in overall length and gross weight. To maximize freight revenue, the solution was to make the freight carrying trailer as long as possible and the tractor as short as possible. Even though freight rates were regulated and established by law, some would say that even the inefficient fleets were guaranteed a profit. This was the case until deregulation. Thus, the COE (Cab-Over-Engine) configuration came into being. Very short COE wheelbase tractors with short BBC (Bumper to back of cab) dimensions were designed to get the most from the length-limited tractor-trailer combinations for line haul trucks using the new interstate highways and/or the traditional existing roads linking America’s cities.

For the truck manufacturers, the solution to the problem with diesel engines was not clear. If you made the traditional inline diesel engine longer to get more displacement and, in turn, more power, you couldn’t fit the whole package of radiator, engine, and transmission in the limited space available in a short wheelbase, short BBC configuration. An alternative solution was needed. Diesel engine manufacturers had gone about as far as they could in increasing the in-line 6 cylinder configuration.

The alternative solution was a “V” configuration engine. Detroit Diesel had the 8V-71, Cummins had the V8-265, Caterpillar the 3408, and so on. With a V configuration engine, more power could be engineered into the limited space of a COE. Now the OEMs had to work with the requirements of a V configuration such as dropped frame rails and changes in engine control linkages, as well as intake air and exhaust plumbing. V configuration engines cost more to manufacture (more complicated cylinder blocks and related machining, multiple cylinder heads, additional cylinder components, fuel system plumbing, etc.) and cost more to install at the truck manufactures. The customer was willing to pay the price as it solved the need for more power at a reasonable cost. More power meant more productivity.

Enter the turbine engine. It was obvious to many people that the turbine could be adapted to line haul trucks. Turbines promised superior performance to inline or V configuration piston power plants of the day, gas or diesel, by being smoother at all RPMs, having greater reliability and durability, and doing away with the radiator and related water to air cooling systems. In addition, turbines could run on a multitude of common liquid fuels. Above all, turbines were thought initially to be able to deliver equal or superior fuel mileage than piston power plants of the day!

Since turbines were relatively vibration free, OEMs could take some of the weight off the chassis to deal with the vibrations of piston engines. Many pieces could be made of fiberglass. Transmissions could be made simpler with fewer gear ratios because the turbine had greater torque at low speed when compared with a piston engine. Lubricating oil consumption, another expense with piston engines, would be practically zero with the turbine. Installing a turbine engine into a COE
configuration had its share of problems for the OEM installation engineer but in the confined spaces of a COE, it could be done with relative ease. Remember, no need to worry about a radiator and related cooling system.

Turbine engineers created retarder systems to provide some of the braking found in diesel trucks. Turbines are free-wheeling, but the retarders incorporated provided a way to approach what diesels could do with their “Jake” brakes (produced by Jacobs Manufacturing). “Jake” brakes use the compression of the engine to act as a retarder reducing wheel brake usage.

American manufactures, such as Ford, Chrysler, International (today called Navistar), Caterpillar, and Mack, all had development projects and some had running prototypes. Chrysler even had near production ready passenger car prototypes with turbine power in the hands of potential customers for real world testing. How could one not expect to see turbine power plants in trucks and even passenger cars in regular production in the very near future?

With so many claimed advantages and so many competent companies working on development projects, why has the turbine engine all but disappeared from view for commercial vehicles? Integrated truck manufactures were ready. The turbines could burn diesel fuel commercially available at truck stops. Technicians could be trained. The whole power plant was much simpler with fewer moving parts. The truck manufacturer distribution systems could provide the sales, parts and service expertise. A turbine powered car was even entered into the Indy 500 mile race. Why don't we see turbines in commercial vehicles today?

Freight is still being hauled down the interstates but today it is essentially 100% diesel power. Gone too, for the most part, are “V” configuration diesel engines. Today’s line haul trucks have in-line diesel power plants. V-8s are the exception for line haul. What happened? Why no turbines? How could so many people be so wrong on their collective visions about the future?

You can get many different answers to the above questions. But two facts are clear. With freight rates then set by law, how could one make money after all the turbine capital costs were tallied? Sure, there were advantages, but there were costs for all the new technology. Production turbine engines aren't cheap. Second, they also burn a great deal of fuel even though much work had been done to make them as efficient under power as diesels of the day. In real world truck testing, the claimed fuel economy gains just weren’t there.

For freight haulers, the answer was clear. With income rates fixed and with the high cost of running turbines, one had no reasonable expectations of making a profit despite all the claimed advantages. A turbine powered truck cost more and it wasn’t as fuel efficient as the diesels that they had in service. Certainly, there may have been potential for better fuel economy from the turbine engine with more development for truck applications but, in the meantime, there was little way to make a profit with turbine powered trucks.

Proposed engine emission legislation began in earnest in 1970. Smog was a major problem in U.S. cities. People didn’t want to live with the “Brown Cloud” as it was then called. Scientist knew that the Brown Cloud was caused by the formation of nitrogen oxides, a by-product of the combustion process in engines: the higher the temperature of combustion, the greater the output of nitrogen oxide or NOx. The turbine engine operated at high temperature to make it efficient. Regeneration systems to heat the incoming air to make the turbine more efficient compounded the problem. To those few studying the causes of emissions, the handwriting was on the wall.

With so much promise and so much fanfare, the turbine engine for trucks never reached fruition. Yes, solutions could be found, but the costs of a practical application kept escalating. You simply can't lose money on each one and make it up on the anticipated volume. The diesel, despite all of its shortcomings and emission problems, seemed to be a more practical answer.

The turbine engine never reached reality for on-highway trucks as the diesels continued to increase penetration over gasoline as further development on turbines ceased, particularly with the pending emission legislation. The diesel remained King! Have you ever stopped to think, however, how the diesel came to predominate over gasoline?
GASOLINE TO DIESEL FOR TRUCKS

No truck manufacturers were promoting diesels in the early 1930s. Diesels were slow speed internal combustion engines found in industrial and marine applications. You couldn’t buy a new truck with a diesel engine. There were no truck dealers to provide sales, service, or parts. Diesel fuel was not available at the truck stops, just gasoline. Diesels just weren’t an option.

Gasoline engines of the day weren’t powerhouses of performance. With the gasoline octane ratings available in the early 1930s, compression ratios of 5:1 or 6:1 were common. The high compression gasoline engine era would not arrive until the early 1950s. The point being that the larger displacement gasoline engines (when compared with gasoline engines in automobiles) didn’t put out much power by today’s standards. The roads then were not the interstates that we have today and 45-50 mph was the normal truck speed. When it came to hills, or worse yet mountains, the low horsepower and torque output caused truckers to use all the gears in the gearbox to pull the grades.

Industrial type diesels were considered but with their slow engine speed, massive comparable size and weight, they really weren’t the answer. Gasoline engines were the most viable answer for freight hauling.

An inventor had a better idea. With the invention and development of a high speed fuel system for diesel engines, he was able to get diesel engine horsepower to equal or exceed the gasoline engine ratings used in trucks. With the increased torque of the diesel, truckers had more useable power, particularly when launching a heavy load or pulling a grade. To prove his point, the inventor installed a diesel engine as a repower of a 1930s Indiana brand truck and proved the reliability, durability and, above all, the fuel economy of a diesel engine in a truck application.

The company he founded to build diesel engines still exists today. Oh yes, he too entered a diesel powered race car in the Indianapolis 500 mile race in 1931. The car holds the track record as the only car to run the 500 mile race without stopping for fuel.

The introduction of the diesel into trucking started just the opposite of what happened with the turbine engine 30 years later. Contrast the differences between the introduction of the diesel and the turbine. No truck OEM endorsed the change to diesel at first. To do so meant losing their own gasoline engine business or the relationship with their gasoline engine supplier. The last thing they needed was someone other than themselves getting all the aftermarket engine parts business.

Diesel fuel was not available at the truck stops of the day, just gasoline. To use diesel powered trucks, a distribution system would have be established. The question: From where would the mechanics who understood diesel combustion and a high speed fuel system come? Even if the OEMs of the day got behind the diesel engine for trucks and they spent a good deal of money training sales, service and parts personnel, in addition to doing all the expensive engine application work to get the diesel engine properly installed, why would truckers want diesel engines anyway? Diesel powered trucks were going to cost more!

The answer was quite simple. Hence the high speed diesel engine’s fuel system inventor’s marketing slogan of the day, “Twice as far for half as much.” A high speed diesel engine in a truck application was far more fuel efficient than gasoline and the diesel fuel cost less. With the conversion to diesel engines, spark plug replacement, setting the ignition points, adjusting carburetors, and frequent gasoline engine overhauls were a thing of the past.

With WWII, people saw the durability and reliability of the diesel engine. After the war, the dieselization rate (percentage of new trucks sold with diesel engines) continued to climb. Supercharging, turbocharging, increased engine displacement, aftercooling, and improved fuel systems helped the diesel engine further increase the performance differentials compared with the gasoline powered rigs. The distribution system for diesel fuel evolved. OEMs promoted diesel over gasoline and
developed their truck distribution systems to promote diesel. Some OEMs developed their own diesel engines. Diesel engine manufacturers established distribution systems to support the OEM dealers and factories.

Yes, diesel powered trucks cost more than gasoline powered trucks. They were heavier too because of increased engine weights, but they were much more productive.

First, the dieselization rate of heavy duty trucks reached essentially 100%. Mid range trucks were dieselized to match the productivity of line haul, and finally, pickup trucks had a diesel engine option. The diesel engine had proven itself the engine of choice. From a humble beginning where the OEMs and customers had to be convinced to support diesel engines, diesel power was the clear winner.

The driving force for change was the performance enhancement with improved fuel economy and the improved reliability and durability of the diesel when compared with gasoline engines. The dramatically improved fuel economy of the diesel compared with gasoline was a game changer. All of the new problems operators exchanged for replacing gasoline engines with diesel could be overcome as the diesel fuel economy had such a dramatic impact on the cost equation of moving freight at the lowest total cost.

Contrast the movement to introduce turbine powered trucks with major manufacturers endorsing it with the diesel engine powered truck market that started with a repowered truck and little, if any, support. How could so many be wrong and one man be on the right track? It all boiled down to the lowest total cost of operation. You don’t have to be 100% in front in every element of the lowest total cost equation, but when you are the least costly on a number of elements, change comes.

We can pose similar case studies such as electric automobiles and diesel electric locomotives. Why, when the electric automobile had 30% of the automobile market did it drop to less than 1% today? Similarly, why did the diesel electric locomotive overtake the steam locomotive? We have an abundance of coal and water in this country. Why the change?

Whether it is trucks, automobiles, or locomotives, one has to look at all the elements that make up the user’s preference and what, in total, takes the lead. So too, the advocates for natural gas usage in trucks have to make their case on all the elements that come to bear on usage and, in particular, the cost implications since a truck is a business asset and not an emotional purchase. As we have seen with turbines and diesels, cost of operation was everything. Our hypothesis says the lowest total cost might be with natural gas as fuel in a large number of truck applications.
Chapter 3: INTERNAL COMBUSTION ENGINES: THE BASICS

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THE OTTO CYCLE

Before one can draw conclusions about whether natural gas can be an economic or power producing alternative to diesel fuel, one needs a basic understanding of internal combustion engines. An engine is nothing more than an energy converter. An internal combustion engine draws in air and fuel, ignites the mixture, and then, uses the expanding force of the energy released in the combustion process (the heat generated by the “fire”) to push a piston down and cause the crankshaft to rotate.

Years ago, the Otto Cycle evolved as the best solution to produce power from fuel. Technically, it is best described as four distinct cycles: Intake, Compression, Ignition (or Power), and Exhaust. As an engine operates, these cycles are repeated over and over again to make power from the fuel used. Generally, the cycles occur in four distinct movements of the piston.

- The intake stroke, (brings in the charge of fresh air and perhaps fuel) as the piston moves down in the cylinder
- The compression stroke, where the air and/or fuel air mixture is compressed as the piston moves up in the cylinder
- The ignition (or power) stroke, where combustion takes place and the piston moves down
- The exhaust stroke, where the piston moves up and cleans out the cylinder of the spent exhaust gases

With the completion of the four cycles, the process starts again.

Yes, there are engines called two cycle engines, such as in motorcycles, but they incorporate each of the four cycles in just two strokes of the piston. As you can imagine, engines come in all displacements (the size of the combustion chamber(s) in cubic inches of displacement) and configurations: inline 4s, inline 6s, V8s, V6s, opposed 4 and 6 cylinders, radials, double and triple rows of radials to name but a few. In each design, the Otto Cycle is used.

All of the Otto Cycle engines fall into two broad categories: spark ignition and compression ignition. In the latter, the air is compressed during the compression stroke (no fuel is added) and when the air is heated enough because of the compression of the air, fuel is injected into the combustion chamber where it burns with the hot air. The burning mixture expands and we get the power stroke. A diesel engine operates by compression ignition. The engine compresses air, diesel fuel is injected into the combustion chamber and we get the power.

In a spark ignition engine, the air generally is combined with the fuel before being injected into the combustion chamber. Whether it is gasoline, natural gas, propane, hydrogen, hythane (a mixture of natural gas and hydrogen), the fuel and the air are mixed together by the use of a carburetor, throttle body or sequential port fuel injection system and compressed before an electrical spark is used to ignite the mixture. With direct injection of gasoline into the combustion chamber with the newest gasoline engines, our definition changes slightly but you still need an electrical spark (usually a spark plug) to ignite the mixture. This paper is not meant to be a treatise on engine design, but rather to provide some basic understanding of diesels versus natural gas fueled engines, which both use the Otto Cycle.

Why was the diesel engine always thought of as more efficient than a gasoline or natural gas engine? The reason is all fuels are not the same. Each distinct fuel used in an internal combustion engine has particular characteristics, one of which is the heat energy it contains for a given unit of measure. A gallon of natural gas has less heat energy in it than a gallon of diesel fuel. We use the term BTUs (as in British Thermal Units) to describe the heat energy in common fuels used in internal combustion engines. From the chart on the next page, we can see how much energy is in various fuels.
As you can see, diesel fuel has more “energy” (the ability to make more heat because it has more BTUs to provide for the expansion of the burning mixture to move the piston downward on the power stroke) than natural gas or gasoline for that matter. For that reason, the diesel engine was always considered to be more “efficient” than natural gas and/or biodiesel.

<table>
<thead>
<tr>
<th>Energy</th>
<th>Structure</th>
<th>BTUs of Energy in a Gallon</th>
<th>Energy Storage (Relative Volume)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diesel Fuel</td>
<td>C_{18}H_{36}</td>
<td>138,645</td>
<td>1</td>
</tr>
<tr>
<td>Biodiesel</td>
<td>C_{18}H_{35}O_{2}</td>
<td>119,000</td>
<td>1.1</td>
</tr>
<tr>
<td>Natural Gas</td>
<td>CH_{4}</td>
<td>85,000</td>
<td>3.7 CNG</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1.7 LNG</td>
</tr>
</tbody>
</table>
EVOLUTION: SUPERCHARING, AFTERCOOLING, TURBOCHARGING, DIRECT INJECTION, AND TURBO COMPOUNDING

Over the years, engine developers have done things with both spark ignited and compression ignited engines to get more power from a given displacement or size of engine. An engine starts in a naturally aspirated configuration. That means it takes in air much as we breathe. For many reasons, as the engine is running, it only gets the combustion chamber about 85% full. Now, if you can force more air into the engine, you can burn more fuel in the required proportion of air and fuel and make more power. Design engineers adapted superchargers (an air compressor mechanically connected to the engine) to get more air into the combustion chamber. The supercharger took more energy to be driven by the engine and the net effect was that there was an increase in the engine’s power. However, fuel consumption went up as did the mechanical load on the engine components.

When air is compressed, it gets hotter. Hotter air is less dense and it cannot burn as much fuel. Intercooling, or aftercooling as it is more commonly called, was a way of cooling down the compressed air from the mechanically driven air compressor or supercharger. With the cooler, more dense air, more power was produced.

A quantum jump was made as design engineers learned how to utilize turbocharging. In a very simplified explanation, we use the engine’s exhaust gas stream to drive a wheel in that exhaust stream that is connected to a shaft connected to another wheel used to compress the air. This is a much more efficient way to get additional air to the engine when compared with a mechanically connected supercharger. In addition, we get altitude horsepower compensation with a turboccharger.

A naturally aspirated engine loses power as it increases altitude because it “runs out of air.” With turbocharging, as you increase altitude, it is easier for the exhaust gases to escape after spinning the turbocharger wheel and, thus, it has more energy to drive the air compressor wheel of the turbocharger. The end result is that either engine design offers the truck operator continuous power going up the mountainside. We even have designs of turbocompounding where the heat energy of the exhaust is used to spin the turbocharger and the energy in the spinning shaft is connected back to the crankshaft to utilize the “free” horsepower to help turn the engine’s crankshaft. The arrangement adds complexity, but it increases horsepower.

So, we had engine development for spark ignited and compression ignited engines occurring, but the diesel still won on the basis of efficiency. The diesel was more efficient because it started with a fuel that had more energy in it per unit of measure. Then, along came society’s wish for cleaner air and the easy comparisons of which fuel was best become more complex.

Engine developers in an attempt to get more power output were trying to build the hottest fire they could in the combustion chamber of the engine and still keep everything together. New metals, new machining techniques, new coatings, and new seals were tried in a never-ending pursuit for improvements. The problem, as the engineers learned, was that the hotter the fire of combustion, the more NOx (nitrogen oxides) was produced. Nitrogen oxides generate the smoke or brown cloud that we saw in our cities.

Initially, if engine ignition timing (the point at which the spark plug fires or fuel is injected into a diesel) was reduced, the temperature of combustion went down, but so did power output. In addition, fuel consumption grew because optimum ignition timing had been compromised in an attempt to reduce emissions.

Further, society decided that it wanted to remove the sulfur from the exhaust. The solution was low sulfur diesel fuel. The cost of refining diesel fuel rose, and the fuel injection systems of the day lost some of the lubricity (lubrication) that the sulfur in the diesel fuel provided.
THE COMBUSTION PROCESS

As emission requirements became more stringent, design engineers had to find a way to reduce the temperature of engine combustion. When adjustments (retarding) to ignition timing reached their maximum impact, the next step was to introduce a gas without any oxygen in it, along with the fresh charge of air, to bring down the temperature. In essence, it was a “heat sink.” That gas was exhaust gas, which contains little or no oxygen. If we could cool the exhaust gas (cooled EGR, or Exhaust Gas Recirculation), it could be introduced into the combustion chamber in just the right amount and decrease combustion temperatures.

Exhaust gas was used because it was available. There was no need to add another tank of “something” on the vehicle that had to be refilled. The exhaust gas used just had to be cooled prior to use. As the processes in the combustion chamber became more complex, electronic engine controls were introduced to make cleaner emissions solutions work.

For a number of years, the formula for meeting the new emission standards was to play with all the variables of combustion to first meet the new standards and then, work on the power, performance, fuel economy, driveability, longevity and all the other parameters that are important to the consumer. Along the way, a number of compromises were made.

With design work going on with both natural gas engines and diesel engines, diesel engines generally were preferred because they used diesel fuel with more BTUs of energy. Then, things changed dramatically. The problem of particulate emissions was much more difficult to solve with engines using diesel fuel.

Take another look at the comparison graphic and review the hydrogen to carbon ratio of natural gas and diesel fuels. CH₄ has a 4:1 ratio of hydrogen to carbon. Diesel fuel has a 2:1 hydrogen to carbon ratio. Hydrogen is what we are really burning in the combustion chamber to make power, but to eliminate the carbon in diesel fuel, we needed to put a particulate trap on the end of vehicles’ exhaust systems to collect the carbon and, from time to time, find a way to dispose of the carbon that was collected.

At some point in time, diesel engine developers realized that they could no longer meet ever-stringent emission standards by playing with all the variables. They needed some relief. To meet the 2010 emission standards, diesel design engineers...
realized they would have to do something outside the combustion chamber. That relief came in the way of using urea which is called DEF (Diesel Exhaust Fluid) with the particulate traps incorporated in 2007. Now the diesel engines needed expensive after treatment to meet emission legislation. The after treatment was more expensive to design and install on the truck as it required its own space, and space on a truck is premium. After treatment added weight and meant the operator would pay for the DEF over the vehicle’s life.

It wasn’t all bad news. Engine combustion experts could tweak the variables that impact combustion chamber efficiency to get more power and fuel efficiency, knowing that the after treatment system downrange of the combustion chamber would be there to filter. The big change came in 2007 with the particulate traps, followed by the DEF system in 2010. No longer could everything be done inside the combustion chamber.

For natural gas engine developers, the solution to emission restrictions was neither as complex nor expensive. The basics were already in place. In tandem with diesel engine development, natural gas engine developers had turbocharging, aftercooling, EGR systems, and full authority electronics. All they had to borrow was the three-way catalyst used on gasoline engines.

A natural gas engine burns clean because natural gas fuel contains very little carbon. It is relatively easy to meet the particulate requirements with no need for particulate traps or DEF. With just a little EGR, a simple three way catalyst, and inherent cleaner combustion, the natural gas spark ignited engine can meet emission requirements through 2018 with less costly solutions than diesel compression ignition engines.

For years, the diesel engine was simply far more efficient. The fuel contained more heat energy and, by its very nature, you could get more power and fuel efficiency from every gallon of diesel fuel. However, with the advent of emission requirements, the comparison changed. The efficiency gap narrowed and it became time to review total operating costs.

To review today’s differences between a natural gas and a diesel fueled engine that meets the 2010 emission standards for the North American markets; consider the chart on page 27.
<table>
<thead>
<tr>
<th>Engine Component</th>
<th>Diesel</th>
<th>Natural Gas</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Engine short block</td>
<td>Same</td>
<td>Same</td>
<td>From the oil pan to the top of the cylinder block, the engine is the same except the piston design and compression ratio are different</td>
</tr>
<tr>
<td>2. Cylinder head</td>
<td>Unique design for fuel injector</td>
<td>Unique design for spark plug</td>
<td>Very similar in design. A hole in the cylinder head for either the fuel injector or the spark plug. Number of intake and exhaust valves used may differ.</td>
</tr>
<tr>
<td>3. Engine accessory drive arrangement – air compressor and any hydraulic pumps</td>
<td>Same</td>
<td>Same</td>
<td>No change in design for multitude of engine driven accessories.</td>
</tr>
<tr>
<td>4. Fuel system</td>
<td>Common rail diesel injection pump and injectors</td>
<td>Natural gas fuel system – a means of mixing natural gas with air.</td>
<td>The heart or basic difference in the engines. Note that the fuel system is the same whether the engine uses CNG or LNG as the supplied fuel.</td>
</tr>
<tr>
<td>5. Exhaust system including the turbocharger, EGR valve, and exhaust cooler.</td>
<td>Same technology</td>
<td>Same technology</td>
<td>Minor differences in turbocharger design – variable geometry versus waste gated. EGR valve to mix air with cooled exhaust gases is essentially the same.</td>
</tr>
<tr>
<td>6. EGR cooler</td>
<td>Same technology</td>
<td>Same technology</td>
<td>May be minor mounting differences but same basic technology.</td>
</tr>
<tr>
<td>7. Spark plugs and ignition system</td>
<td>Not Required</td>
<td>Add to engine</td>
<td>Along with the fuel system, the use of an ignition system differentiates the two engines. Ignition system uses modern coil over plug design.</td>
</tr>
<tr>
<td>8. Flywheel or flex plate mounted to the crankshaft.</td>
<td>Same</td>
<td>Same</td>
<td>Difference is whether the engine will be used with a manual or automatic transmission.</td>
</tr>
<tr>
<td>9. Engine oil lubrication system</td>
<td>Same</td>
<td>Same</td>
<td>Both engines use spin on combination full flow and by-pass oil filters. Different low ash oil is used in the natural gas engine.</td>
</tr>
<tr>
<td>10. Engine cooling system</td>
<td>Same</td>
<td>Same</td>
<td>Both systems utilize a water pump to circulate coolant through the entire cooling system.</td>
</tr>
<tr>
<td>11. Electronic engine controls</td>
<td>Very Similar</td>
<td>Very Similar</td>
<td>Minor differences due to fuel used and ignition system.</td>
</tr>
<tr>
<td>12. Engine and system diagnostic controls</td>
<td>Same</td>
<td>Same</td>
<td>Basically, a laptop computer that can read the engine control system, read fault codes, and record data.</td>
</tr>
<tr>
<td>13. Engine starters and battery charging systems</td>
<td>Same</td>
<td>Same</td>
<td>Numerous options to meet customer requirements.</td>
</tr>
</tbody>
</table>
CNG and LNG

Natural gas is a fossil fuel that comes from underground or from other sources. Natural gas in the ground contains methane, ethane, propane, butane, pentane, and traces of hexane and heptanes. For the purposes of natural gas as a transportation fuel, the vast majority of the “tanes” are removed to leave methane which is CH₄, one carbon atom and four hydrogen atoms. It is the hydrogen that we burn in the combustion chamber of a natural gas engine to make power. When natural gas or methane is burned, the main products released are carbon dioxide and water.

Natural gas is colorless, odorless, non-toxic, and lighter than air after the “tanes” are removed. An odorant is placed into natural gas to provide detection by the human nose to indicate the presence of natural gas; otherwise, we would not know of its presence. When you smell natural gas, you smell the odorant.

Methane also is obtained from refuse sites. As the refuse materials decompose, natural gas is emitted. To prevent the methane generated from igniting, the methane is collected by a series of underground pipes at a central point. The collected gas is flared or burned to prevent a build-up of the gas. In some locations, this collected gas is used in industrial natural gas engines to generate electricity. The fuel, methane, is “free” and the end product, the electricity, is sold commercially. The revenue from the sale of the electricity provides for the system’s cost. The industrial natural gas engines burn whatever gas is generated, contaminates and all.

The methane gas collected from refuse sites generally contains siloxanes, which are produced from the decomposition of plastics. These siloxanes are like miniature beads of glass. They can wreak havoc with the industrial natural gas engines as they burn the methane generated from the refuse sites, but with the revenue from the generation of electricity, the industrial natural gas engines are rebuilt and returned to service. Remember, it is not an exercise of generating electricity at the lowest total cost, but rather one of getting rid of the methane gas at the refuse site.

The alternative to collecting the methane gas and burning it in a controlled way is to risk the refuse site catching on fire from the escaping methane gas. If the refuse site is closed, that is no more refuse is brought to the site, the process of methane gas escaping to the atmosphere would continue for about 10 years until decomposition is completed. Besides providing an electricity source, this process helps solve the problem of the methane gas that collects at a refuse site.

Another source for methane is biomass from plants and other waste products such as that generated at dairy farms. In many instances, methane, once thought a problem, has now become part of an overall solution.

As we look at the big picture of natural gas, we have discovered an increasing supply in the United States: underground, at refuse sites, and from an increasing number of animal and plant waste producing sites. Contaminants, such as siloxanes, are being commercially removed, resulting in commercially-viable, natural gas generating systems.

For example, refuse trucks that haul municipal waste can be powered economically by natural gas. The refuse site generates the methane gas which is collected. Then, siloxanes and other contaminates are removed from the gas that can then be used to refuel the refuse trucks. After the refuse trucks are fueled, any surplus can be used to power the municipal bus fleet and, if enough remains, it can be sold commercially to other natural gas vehicle users.

The information above describes the current sources of natural gas: underground deposits, fuel generated at refuse sites, and other biomass sources. Now the question, why is natural gas sold in two forms: CNG (Compressed Natural Gas) and LNG (Liquefied Natural Gas)? The simple answer is the vehicle range needed by the end-user.

In a diesel or gasoline powered vehicle, the fuel (which in both cases is a liquid) is stored in onboard tanks. On a typical truck or tractor application, we have saddle tanks for diesel fuel. The amount of tank fuel is a function of how far the owner or operator wants the vehicle to travel before refueling. If the vehicle is used in route distribution and comes home every night and can be refueled on site, the decision may have been made to reduce the amount of fuel to that needed to complete the daily route with a little extra for...
reserve. Here the amount of fuel on board is being replaced by the weight of the product being hauled.

Conversely, for a line haul truck, enough fuel is needed on board to travel long distances without stopping to refuel or to control the cost of fuel purchased. Again, a decision is made as to how much fuel will be on board and its weight traded against the weight reduction of the product being hauled.

Similarly, a natural gas powered vehicle is generally spec’d with enough natural gas on board to complete the route of the vehicle. In the case of a vehicle using CNG, there is enough fuel on board to equal the energy content of the diesel fuel. The CNG tank would have a maximum “full” pressure of 3,600 psi; that is, a full fill would be to fuel (fill) the tank to a maximum pressure of 3,600. As the natural gas fuel is used by the natural gas engine, the pressure drops in the tank.

CNG tanks come in different sizes, capacities and composition. There are steel tanks, aluminum tanks, and composite material tanks. Each design has its own advantages and disadvantages, as well as its own capacity constraints and associated costs. To get the range that the operator wants, the “standard offering” tanks are used in multiples to get enough fuel on board. On a refuse truck, you may find multiple tanks on top of the packer body. On regular trucks and tractors, you will generally find a collection of CNG containers or cylinders placed behind the cab stacked horizontally.

A spark ignited natural gas engine requires an inlet fuel pressure in the neighborhood of 75-125 psi to operate normally. A fuel pressure regulator drops the CNG fuel tank pressure down to this range. As the pressure in the CNG tank drops to the 125 psi range, the natural gas engine begins to stumble as it “runs out of gas” much like what happens when we run our gasoline powered vehicle out of gasoline. Thus, you put enough CNG cylinders on board so that you complete the duty cycle of the vehicle without running out of fuel, just as you do with diesel fuel or gasoline.

LNG (Liquefied Natural Gas) is, as the name implies, a liquid form of a gas. If one takes CNG (Compressed Natural Gas) and cools the compressed gas to minus 260 degrees Fahrenheit, the gas turns to liquid. It becomes a cryogenic fuel. LNG takes up 1/600 of the space of CNG in its natural state. Thus, one can get more fuel on board with LNG than with a collection of CNG cylinders.

Think of an LNG tank as a giant thermos bottle. It is holding the fuel at minus 260 degree Fahrenheit at a pressure of about 150 psi. The tank is well insulated. The “R” value of the insulation is about “R 1,000.” Contrast that with the insulation in a home’s attic of “R 32.”

LNG fuel is used when an operator is concerned about vehicle range. At present, there aren’t many LNG fueling stations, and one must plan the route of the vehicle or risk running out of fuel. To get the equivalent amount of fuel on board as diesel fuel, the LNG tank(s) will be about 1.7 times the size as a traditional diesel fuel tank. Although the saddle LNG tank might look the same size as a diesel fuel tank, one needs 1.7 times the tank capacity to have the equivalent amount of fuel and range as diesel fuel.

LNG fuel generally costs more than CNG because there are more steps in the process and those steps cost additional money. Using large electric motors to drive compressors, we can compress the CNG to the current standard of 3,600 psi. To get LNG, we have to take the next step and cool the CNG to minus 260 degrees Fahrenheit which takes more energy. More steps mean more expense, just like the cost of premium or higher octane gasoline. There are extra steps to get higher octane gasoline and the value-added product costs more per gallon.

An operator faces a major difference when considering CNG or LNG and that is the fact that an LNG tank might be venting natural gas as part of the process of holding the fuel at such a low temperature. In a CNG tank system, the CNG can be completely shut off. Turn the valve(s) to off and the fuel is contained in the cylinders much as if you shut off the valve on the propane tank for your gas grill. No gas can escape until you are ready to use it, but that isn’t the case with an LNG tank.

Inside the LNG tank, there is liquid natural gas and some natural gas in a gaseous state. Near the top of the filled LNG tank, there is a little space for natural gas as a gas. This is the gas that flows to the engine to be burned in the cylinder when it is mixed with air and ignited by a spark plug. This is the ongoing process; liquid is turned to gas and is used to fuel the engine. The engine doesn’t know
the difference as it draws the fuel as a gas. This is true even with the high pressure direct injection (HPDI) systems discussed elsewhere. As the gas is used, more space is available in the LNG tank and more liquid changes to gas until the supply of LNG is exhausted and no more fuel (liquid or gas) is available and the tank must be refilled.

If the vehicle’s engine is off, some of the liquid is changing to gas. The LNG tank is not designed to contain high pressures as is a CNG tank. Thus, the excess pressure generated when the LNG changes to a gas must be vented to the atmosphere. If you look closely at an LNG fueled truck, you will see a vent line from the LNG tank generally running up the back of the cab where it vents to the atmosphere.

Remember, the CNG was cooled so that it is 1/600 the space as a liquid as when it was a gas in its natural state. Holding a liquid at minus 260 degrees Fahrenheit for a long period of time is a difficult engineering exercise, particularly when the vehicle is parked. Venting a little natural gas to the atmosphere is an acceptable compromise provided that you don’t pull the vehicle into the confined space of a repair shop where the natural gas vents into the building.

When sitting outside, the relatively small amount of natural gas that may vent to the atmosphere with an LNG system is not a fire hazard as the gas quickly mixes with the abundant air and there is no fire or explosion hazard. However, in a confined space, it can be a real problem. You don’t want LNG tanks venting to a natural gas heater installed in the service bay that has an open flame burning natural gas as a way of heating the bay. In another section, we’ll review outfitting a shop for natural gas powered vehicles.

When a line haul tractor pulling a trailer is used to haul freight, the minute amount of natural gas that may vent from a LNG tank is of no consequence. The LNG fuel is being converted to a gaseous state and being used by the engine at such a rate that little, if any, fuel is venting to the atmosphere. It is only when the vehicle is not in operation that the conversion of the liquid to a gas that is vented becomes a problem.

The questions an owner/operator must consider when deciding between diesel and natural gas are: How much fuel do I want on board and how much weight or fuel tank space penalty do I want to incur? The trade off with natural gas is that it takes more weight and more space. If the fuel is substantially cheaper, then, it becomes another factor in the equation of cost per mile. With the price of diesel fuel escalating, the outcome of the cost per mile equation generally is more favorable to natural gas.

We don’t give much thought to refueling a truck with diesel fuel or our own passenger cars with gasoline. You pull up to the nearest pump, remove the fuel tank cap, insert the appropriate nozzle, and begin fueling. With the automatic cutoff feature of the nozzle, when the tank is full, the fueling automatically stops. We replace the fuel tank cap, pay the bill, complain about the price, and drive away. With natural gas, the process is a little different.

We don’t think of buying gasoline or diesel fuel as a piecemeal process, but it is. First, the petroleum must be recovered from underground and then, transported to the refinery. Next, the barrel of oil must be refined into the products we want. Then, the refined product is stored. To get the product to us, there are pipelines and delivery vehicles moving fuel to our favorite station where it is generally stored underground in large tanks. When we pull up for a fill, there is the added cost of pumping the fuel from the ground and into our tanks. In addition to these costs, we need to include federal and state taxes. All of these cumulative costs are totaled and presented to us as the price per gallon.

The delivery of CNG or LNG is very similar, but there are a few optional differences. If we are a user of natural gas for vehicles, we have some decisions to make. Are we just going to buy CNG or LNG from a commercial seller at a fuel station such as a truck stop, or are we going to have our own fueling station?

If our facility is near a natural gas supply line, we might elect to build a natural gas fueling station on our property. The next question is whether it will be a fast or timed fill (or something in-between) station. Suppose we have a limited number of natural gas powered vehicles such as a municipal fleet of natural gas powered refuse trucks that return to the yard every night. These vehicles are parked for the evening, and we could have a pumping station to compress our supply of natural gas.
gas for the CNG tanks on board the trucks. Our compression station would be of a size that it could fill all the truck tanks over some period of time, say 10 hours. Our facility would have individual supply lines to each space where the truck is parked. When the operator returns from the day’s duty, he or she “plugs in” the supply line to the truck and it is automatically fueled over the next couple of hours. Before the operator leaves the next morning, the CNG line is “unplugged” and the vehicle leaves the yard with a full system of tanks with CNG.

The above type of natural gas compression system is sized to meet the total truck demand for fuel in the allotted time for fueling. This type of slow fill system is popular with refuse fleets, school buses, and municipal buses where the number of vehicles and time out of service is known. If you add more vehicles, you add additional gas compression equipment. In addition, it is generally easier to get a full tank of CNG since the compressed gas has time to cool sufficiently to insure a full tank of fuel at 3,600 psi.

A different scenario is created when vehicles arrive and depart throughout the day. Periodically, the hub may have a large number of vehicles that need to be fueled with CNG quickly before they return to service, such as a municipal bus fleet just before rush hour begins. In this situation, the demands on the compression system have increased. The system will need to run continuously to put compressed CNG into some large storage tanks at the facility to allow vehicles the opportunity to simply pull to the CNG fueling station, refuel, and return to service. This would be similar to a hotel that needs a system to supply plenty of hot water in the morning when the vast majority of guests are getting up and want a hot shower. During the rest of the day, the hotel doesn’t need to heat as much water.

The big difference here is cost. The faster you want to compress natural gas and the faster you want to refuel vehicles with CNG, the greater your capital costs. For fleets with a large number of vehicles, all one has to do is factor in the costs in the equation to reach the cost per equivalent gallon of CNG to see if natural gas makes sense for them.

For a number of natural gas users where the volume of gas to be used is high, commercial companies will quote a price. The prices quoted could be for: a station you own, maintain, and pay for the gas supplied; a station you own, they maintain, and you pay for the gas supplied; or a commercial operation may guarantee you a price per equivalent gallon of natural gas (remember natural gas is sold on the basis of equivalent BTU content as diesel fuel) for a number of months or years if you will guarantee the purchase of a minimum number of gallons per the same period. Obviously, there are numerous combinations of how the costs are covered. As with any business decision, a comprehensive analysis must be made.

If a commercial fueling operation has a source of natural gas nearby, they will build a CNG station to serve trucks and cars alike just like a major truck stop. They project the number of customers, number of gallons to be purchased per unit of time, costs of operation (manned versus unmanned site), cost of maintenance of the compression and fueling equipment, etc. The commercial operator may even purchase natural gas futures on the open market to smooth the price swings in natural gas. The price of the CNG will vary with the risk undertaken. The more a commercial operator can insure the volume sold and the cost of the natural gas, the more costs and profits can be controlled. This enables the operator to enter into a mutually beneficial contract to supply fuel to a natural gas fueled fleet.

Business decisions in the operation of a CNG or LNG refueling station are no different than those made to establish recharging stations years ago when 30% of vehicles in use were electric. With the advent of cheaper alternative gasoline powered automobiles, the electric battery charging stations disappeared. With the promise of today’s electric cars, the economics of the battery recharging station is being revisited.

For most CNG vehicle users, the questions are how many vehicles to operate and how much fuel will be used. At some point, a dedicated onsite fueling station can be financially justified.

LNG’s story is a little different. You need a pretty big operation to justify the natural gas compression operation and the cryogenic operation to turn the CNG into liquid and to store it. A commercial LNG facility is very similar to a refinery. There are economies of scale where volumes make the investment worthwhile. Notice that a diesel operator doesn’t have a refinery in his back yard. It
would be cost prohibitive, even if you could get a permit, and the size of your fleet would be enormous.

When fueling with LNG, the refueling operator needs training to deal with a cryogenic liquid. The training is not rocket science, but some basic precautions must be taken; personal protective equipment must be worn. The refueling facility’s size (CNG or LNG) determines how fast the vehicle can be refueled. Remember though, there is more to a refueling stop than just the fueling. Time is spent checking the fluids, air in the tires, noting any maintenance required, etc. Contrast what happens when you refuel your car with gasoline on a trip. Refuel the car, use the rest room, purchase a cup of coffee, and be on your way. Refueling a vehicle with CNG or LNG is no different.

With an LNG delivery truck system, you can have the system deliver both CNG and LNG. When the LNG tanker delivers the LNG, the refueling operator can load the LNG using vehicle tanks right from the LNG tanker. Some of the LNG could be converted back into CNG with a small compression station on site. If you had no access to a natural gas supply line, this system could be made to work or one could deliver CNG in “tankers” holding LNG. The bottom line is cost; at what cost can CNG or LNG be delivered and how does that compare to the cost of diesel?

The LNG supplier has a fleet of trucks delivering LNG to truck refueling stations across the country. Just as with petroleum products, there is a range of miles from the LNG facility to the refueling station that makes economic sense.

As the demand for natural gas fueled vehicles increases, so does the demand for an increasing number of LNG and CNG refueling stations. With the CNG station, the compressor operations can be close to the refueling station. All you need is a supply of gas to the compressor. A CNG storage facility can be built near the compressor. With LNG, the economies of scale are such that the LNG product will be trucked from the LNG generating facility. Remember, you can’t push LNG through a pipeline as you have no way to keep it cold and in a liquid state.

The question of CNG and LNG safety always surfaces in discussions of alternatives to diesel and/or gasoline. Natural gas as a fuel in commercial vehicles can be just as safe, or safer, than diesel fueled vehicles. CNG and LNG tanks are tested to be dropped, involved in collisions, shot at with weapons of all kinds, and every other “accident” you can think of in today’s environment. If a natural gas holding tank (CNG or LNG) is breached, it vents harmlessly to the atmosphere. It takes a proper mixture of natural gas escaping from a vessel to mix with air before it becomes combustible. Contrast that with gasoline and/or diesel fuel that is heavier than air and pools at the accident scene and can come in contact with any number of ignition sources.

Natural gas, whether CNG or LNG, usage entails some risks. Americans have learned to minimize those risks and many use natural gas to cook food or heat their homes. Using natural gas as a transportation fuel encompasses risk. Those risks appear to be no greater than those of using diesel fuel and/or gasoline.
PROPANE

Propane, a molecular formula of C₃H₈, is normally a gas that is compressed to make it a transportable liquid fuel. It is a by-product of natural gas processing and petroleum refining. The mixture of propane and butane is what is commonly known as LPG (Liquefied Petroleum Gas) or LP gas that is used as a transportation fuel.

Propane contains an odorant, usually ethanethiol, so a leak can be detected by smell. In the processing of natural gas, propane, butane and ethane are removed to prevent the condensation of these volatiles in natural gas pipelines. Most of the propane used in the United States is produced domestically for home heating, barbecue grills, portable camping stoves, and RVs as well as fuel for spark ignited internal combustion engines. In some places, it is referred to as autogas.

Unlike natural gas, propane is heavier than air and will sink to the ground if it leaks from a container. The combustion of propane, as in an internal combustion engine, is much cleaner than gasoline though not as clean as natural gas. The difference in the cleanliness is caused by the number of carbon atoms in a molecule of propane, which has 91,690 BTUs of heat energy per gallon.

The advantage of propane when used as a transportation fuel in automobiles is that it can be kept in a liquid state at a moderate pressure in a tank that is not excessive in cost compared with gasoline. It burns cleaner than gasoline but has less energy content than gasoline, which means it takes more propane to go the same distance as gasoline. The octane rating of propane is higher than that of gasoline, but less than natural gas.

The fueling infrastructure for propane as a transportation fuel is much more developed than that of natural gas. People who drive gasoline vehicles converted to run on propane can always fill the main vehicle tank from a 20 pound barbeque propane cylinder in order to reach a refueling site.

Propane could be used as a transportation fuel in heavy duty trucks, but it requires the fuel to be stored in a pressurized container which presents its own set of safety concerns. As with natural gas, propane does not contain as much heat energy in the form of BTUs as diesel. Therefore, you need to put more fuel on the vehicle to equal the diesel range. When compared with diesel, natural gas and propane both require heavier and more expensive fuel tanks.

Since propane and natural gas have similar fuel tank requirements and propane already has a better distribution network, why not promote propane as a more viable alternative to diesel fuel? The reasons are simple and cost-related.

- Propane is a by-product of natural gas processing or petroleum refining; availability depends on finding a use for the primary product.
- Because it is a by-product, the cost of propane on a BTU basis is higher than natural gas.
- Propane provides less power per equivalent gallon of natural gas, requiring an internal combustion engine to have more cubic inches and/or be more highly turbocharged to get the same horsepower as diesel fuel.
- Propane’s increased carbon atoms present emission problems that would have to be overcome to achieve horsepower and meet emissions standards.
HYDROGEN

Some might argue to skip any discussions of changing to natural gas and move straight to hydrogen as an alternative fuel for heavy duty trucks. Hydrogen provides clean combustion; there is no carbon in hydrogen. The by-products of hydrogen combustion are heat and water.

It has been demonstrated as fuel for spark ignited engines in passenger cars. Hydrogen has been mixed with natural gas (a mixture of approximately 20% hydrogen and 80% natural gas called hythane) and shown to improve the combustion characteristics of natural gas in spark ignited natural gas engines.

When hydrogen has been used as a fuel for internal combustion engines in automobile demonstration projects, the compressed fuel tanks holding the hydrogen are at much higher pressures than that of natural gas. Pressures in the fuel tanks are in the neighborhood of 10,000 psi to get enough range. Compare that with the 3,600 psi of natural gas tanks.

Hydrogen has also been proposed as the fuel for fuel cells to power electric vehicles without the use of internal combustion engines. After all, hydrogen is the most abundant and simplest element in the universe. Hydrogen used commercially in cars, however, is produced from hydrocarbons such as natural gas. It is anticipated that hydrogen will be commercially viable and environmentally friendly only when it can be extracted from water using renewable power sources such as wind or solar.

While we currently have the start of a natural gas fueling infrastructure for heavy duty on-highway trucks and tractors, we have no infrastructure for hydrogen distribution. In a chemical process we can make hydrogen from natural gas. Why, then, try to skip the development of a natural gas distribution system for fueling heavy duty vehicles? The total costs of a hydrogen distribution system would be far greater than trying to expand the natural gas fueling network already started.

Others have examined the cost of hydrogen as a fuel and found the projected fuel costs to be higher than natural gas. Remember, you generally start with the cost of natural gas that you use to generate the hydrogen fuel at additional cost. Add the cost of starting a hydrogen distribution network and you quickly have a very large hurdle to overcome to get to a hydrogen fuel economy.

Without some technology breakthroughs using solar or wind energy to generate hydrogen, natural gas remains the answer as a fuel alternative.
DUAL FUEL SYSTEMS

Otto Cycle engines were discussed in the first section of this chapter, along with two alternatives: spark and compression ignition engines. There are variations of these two classifications and the following will provide some discussion of the variants: dual fuel and HPDI (high pressure direct injection) as they apply to diesel engines.

The military has always had an interest in multiple fuel engines. In wartime, the availability of one specific fuel can be problematic. Therefore, military planners have been supporters of engines that could burn more than one fuel. To get multiple fuel engines, engine designers have had to make compromises where optimization of combustion in the engine on any one fuel is compromised to allow for the use of multiple fuels.

In the civilian environment, operators have asked for engines that could burn more than one fuel. The term “dual fuel” is used to describe an engine that can run on two fuels and the change-over to an alternate fuel doesn’t require any action on the part of the operator. At best, the driver flips a switch to change fuels. The dual fuels are used to extend the vehicle’s range without refueling and/or to gain a fuel cost savings using the less expensive fuel with the ability to change fuels as price changes.

With the dual fuel engine, the basic concept is to reduce the fuel rate or usage of diesel fuel being injected into the combustion chamber and replace it with natural gas which is sprayed in a controlled manner or “fumigated” into the intake manifold. The mixture of natural gas and air is drawn into the combustion chamber, compressed, and then, an injection of diesel fuel ignites the mixture just as when compressed air alone is injected with diesel fuel. The emissions are very clean as the engine is running on natural gas and using a small burst of diesel fuel to ignite the combined mixture.

The challenge for engine developers is creating a smooth working fuel control system. The diesel burn rate needs to be reduced at the same time that natural gas is introduced into the intake manifold in the proper amount to make the whole system seamless to the vehicle’s operator. The vehicle generally has CNG tanks on board to provide the natural gas. A pressure regulator provides the means of controlling the flow of natural gas to the engine. The engine will not run on natural gas alone as there is no provision to provide the spark to ignite the mixture. Conversely, the vehicle can operate on diesel fuel until the diesel fuel supply is exhausted.

The end result is that the engine can burn lower cost natural gas, the emissions are cleaner with the natural gas, and the operator has a choice of fuels. As mentioned before, there are some compromises with this dual fuel system; engine development is truly the “science of compromise.”

The engine will not produce the same horsepower on the combination diesel fuel/natural gas as it can with diesel only. Remember, there are limits as to how much you can compress a mixture of natural gas and air before detonation begins. Diesel engines have a compression ratio of 16:1, while the compression ratio for natural gas is approximately 12:1. Any ratio higher for the natural gas engine risks detonation, particularly when the engine is expected to pull full power. If you had a combustion chamber full of a natural gas and air mixture in the correct proportion with a 16:1 compression ratio, detonation of the mixture would ensue as it is an untimed explosion (rather than a controlled burn) resulting in structural damage to the engine.

Detonation destroys engines! Cylinder pressures rise dramatically before combustion starts. Detonation causes aluminum pistons to crack and distort, cylinder liners to crack, and rod bearings to be pounded out. There is tremendous shock load on the engine. Detonation is the opposite of a controlled combustion that starts at the spark plug when ignition occurs and travels (known as the flame front) to other parts of the combustion chamber. Engine designers sometimes refer to detonation as the “death rattle” and do everything they can to eliminate it in an internal combustion engine.

To prevent the onset of detonation, the fuel rate of the natural gas flow or fumigation into the engine is controlled so that the mixture of natural gas never exceeds some predetermined amount where detonation will occur. Thus, diesel fuel is removed and replaced with natural gas, but only to a point below the limits of detonation. With the detonation limit established, the reduced energy from the diesel fuel injection rate is never replaced fully. This translates to a 400 horsepower diesel engine operating like a 350 horsepower engine when
using natural gas via fumigation of the intake system.

Dual fuel operators, thus, saw the emissions and fuel cost advantages of natural gas when in the cruise mode with the vehicle, but had to rely on pure diesel if they wanted to get the maximum horsepower they purchased with the pure diesel engine.

Dual fuel engines were popular in the early 2000s. Conversion to a dual fuel setup was relatively easy with incremental cost, but this option lost favor as emission standards became more stringent. Even with a minimal diesel fuel burn rate, the 2010 emission certified diesel engine needed all of the post combustion chamber emission solutions, particulate traps, regeneration systems, and DEF, to be certified as emission compliant. Because full power could not be achieved burning natural gas, as it could with full diesel, and because a full diesel emissions system was still required, the demand for dual fuel systems in the on-highway truck market was greatly curtailed. Cost and performance compromises reduced dual fuel popularity.

Dual fuel has another meaning and it is coming into vogue these days as OEMs offer gasoline engines in pickup trucks that can run on gasoline and switch over to natural gas. In this case, both engine configurations, gasoline and natural gas, are spark plug ignited and have the same detonation limits controlling their performance. In a modern gasoline dual fuel engine, a natural gas fueling system provides the fuel and the ignition system used with gasoline provides the spark. Rather than converting gasoline (a liquid) to a gas via a carburetor or fuel injection system in gasoline operation, natural gas (as a gas) is introduced into the engine intake system. The mixture of natural gas and air is introduced into the combustion chamber where it is compressed and ignited by the spark plug and power is produced. Note that the gasoline has an octane rating (a measurement of how resistant the fuel is to causing detonation or spark knock) of 87-93 depending on which grade the operator purchases while natural gas has an equivalent rating of 120 octane.

The advantage to this system is the operator can operate on the less expensive natural gas where available and not fear running out of fuel if used outside the normal operating area as the operator should find gasoline readily available. Why go to the added expense of this dual fuel system? The answer is simple; take advantage of the lower costs of operating a vehicle with natural gas. If you burn much fuel, the initial incremental cost of the system can be recouped.

As engine developers explored dual fuel systems and learned about their limitations, the HPDI concept evolved. With HPDI, diesel fuel is “injected” in controlled amounts directly into the combustion chamber of a typical diesel engine. The current production Westport Innovation offering is a good example of 15 liter HPDI engine. Navistar is reportedly developing a 13 liter HPDI type engine.

The concept of HPDI is to inject a small amount of diesel fuel into the combustion chamber, as per normal compression ignition engine practice, to start the combustion process. This is followed by a metered amount of natural gas using the same injector that injected the diesel fuel. To start the ignition process, the same amount of diesel fuel needs to be injected as would be used to make the engine idle. The “injector” in this design has the dual capability of injecting the liquid diesel fuel under high pressure to atomize the fuel to begin the ignition process followed by a metering of natural gas under pressure (as a gas, not as a liquid) into the combustion chamber while the combustion is already taking place. The variation in the amount of natural gas “injected” into the combustion chamber determines the horsepower and torque output of the engine.

There is only one injector for each cylinder that meters the correct amount of diesel fuel and the same “injector” provides the correct metering of natural gas. The HPDI injector is the heart of the system and is a marvel of engineering. It is usually optimized as to its position in the combustion chamber along with the two intake and two exhaust valves used in a modern diesel engine. The “real estate” in a modern engine cylinder head is expensive; the science of compromise takes effect and space for the valves competes with the size of the injector. The valves need to be as large as possible for better breathing and the size of the injector nozzle needs to be as small as possible to allow for the larger valves. There is no room for a separate diesel fuel injector and natural gas
injector unless engine performance compromises are acceptable.

Along with the specialized HPDI injector, a way to keep the gas pressure elevated is needed to inject the natural gas into the combustion chamber where the pressures of the compressed air and increasing pressures of the combustion of the diesel fuel and air must be overcome. Fumigating an intake manifold is one thing; forcing natural gas into a combustion chamber with its dramatically higher pressures inside is an entirely different matter.

Now, consider what's included in the HPDI design:

- Natural gas fuel is being injected into the combustion chamber where the fire is already taking place.
- An HPDI engine is essentially the same as a diesel engine upon which it is based. No need to change to a lower compression ratio piston or make other major modifications.
- The HPDI engine can produce the same horsepower, the same torque, and generally, the same fuel economy as a diesel only engine.
- The engine runs on approximately 95% natural gas, a less costly fuel.
- Over the life of the vehicle, there can be very significant fuel cost savings.

Limitations include:

- The unique injector is expensive to produce.
- The other requirements to operate the system, such as a way to keep the natural gas pressure elevated, add to the cost of the system.
- With today's stringent engine emission requirements, the HPDI system still needs some type of after combustion exhaust treatment. This requirement adds cost, weight, and complexity.

Generally, HPDI system trucks run with LNG fuel supply tanks. Given the horsepower these 15 liter engines can produce, they are generally in heavy haul transport where the LNG fueling stations are along the routes traveled. The vehicle will have a large LNG fuel tank sized for the planned mileage between refueling, as well as a similarly sized but much smaller diesel fuel tank. It may have a DEF tank as part of its total emission package, depending upon its design and level of emission certification.

Dual fuel and HPDI engine systems are simply engineering variations on the two basic types of internal combustion engines: spark and compression ignition.
OPERATIONAL CONSIDERATIONS

In operation, users will find a natural gas fueled engine much quieter than a conventional diesel engine. Although diesels have become quieter in recent years due to advances in pilot injection of diesel fuel with electronic controls, the natural gas engine is quieter due to the spark ignition. In a spark plug ignited system, the flame front travels from the tip of the spark plug across the combustion chamber as opposed to the combustion of the diesel fuel and air mixture in a diesel engine which occurs all at once. The “all at once” provided the traditional diesel engine “knock” or characteristic noise. With today’s pilot injection of diesel fuel, the “knock” is much quieter, but the natural gas engine is quieter still.

With the HPDI system, there can be less noise than with a traditional diesel as only a very small amount of diesel (perhaps 5% of the total fuel used) is used to light the compressed air/diesel fuel mixture while the natural gas is forced into the combustion chamber where the ignition or “fire” has already been started. With either system, HPDI or spark ignited natural gas systems, the noise is noticeably less.

The lack of noise is so pronounced that new users to natural gas suspect that the air compressor is “knocking” or has some problem. The “knocking” noise was always there, but they couldn’t hear the normal noise as it was masked by the normal diesel combustion noise.

One of the transition problems is that when a driver goes from a diesel engine to a natural gas engine it lacks noise. Drivers equate noise with power and may complain that the natural gas engine is “down on power.” With a little explanation, the drivers begin to appreciate the reduced noise level in the cab.

Generally, a properly set up natural gas fueled engine will start better in cold weather than a comparable horsepower diesel. The reason is the nature of the natural gas spark ignition system compared with a traditional diesel injection system. In a diesel, in areas where cold soak temperatures are anticipated, coolant block heaters may be used on both. In a diesel, compression heat is needed to start the ignition process. This is no small feat when the engine is cold and all the metal parts act as a “heat sink” during the start up period.

The diesel engine is more efficient because it operates with a higher BTU fuel and it uses a higher compression ratio to get more power from each power stroke. However, today’s natural gas engines, whether they are spark ignited or HPDI, can closely approximate the horsepower and torque of a diesel at a substantially lower fuel cost. In a theoretical discussion of natural gas versus diesel, the diesel engine will win every time. Consider cost in the discussion, and the natural gas engine quickly wins.

The diagnostic procedures on a diesel engine and a natural gas engine are, for all practical purposes, the same. A technician uses a laptop computer connected to the engine’s ECM (Electronic Control Module) or “Brain Box” as some would call it to get fault codes and plan a course of corrective action. A common complaint on a spark ignited natural gas engine could be a detected “miss” in the engine performance. Using the proper diagnostic procedures, the technician could determine which plug, ignition coil, etc. needed attention.

In-cab fuel gauges tell the vehicle operator the amount of natural gas in the fuel tanks whether CNG or LNG. The gauges are as accurate as those used with diesel fuel with single or multiple tanks.

At the vehicle refueling station, the procedures to make sure a vehicle is ready for the road are very similar. Make the usual non-fuel fluid checks, make sure the vehicle has adequate natural gas on board for the duty cycle, review any driver write ups, take correction action, and put a safe vehicle back on the road.

Part of the vehicle safety check is to make sure the methane (natural gas) detectors are operating properly. Remember, natural gas is lighter than air and if it escapes, it will rise. There are no detectors on the truck to know if diesel fuel is leaking. If one were outside and saw diesel fuel leaking from a saddle tank, appropriate action would be in order. If in the cab, the operator really has no way of knowing if fuel is leaking other than the fact that he may be using an abnormally high amount of diesel fuel. A diesel fuel leak will contaminate the ground if unchecked. A natural gas leak will generally be vented harmlessly to the atmosphere.

The fueling of a natural gas fueled truck with CNG is a simple procedure, basically the same whether
it is a fast or slow fill system. A CNG hose from the dispenser is connected to the vehicle and CNG flows into the vehicle tank(s). The dispensing system prevents overfilling by monitoring the fuel pressure resistance, how much fuel (by measuring the vehicle tank pressure) is already in the tank. When it reaches a certain limit, the dispensing system shuts down without driver or fueling attendant's attention required.

In the case of an LNG system, it is a cryogenic fuel which requires proper care. Specifically, the fueling attendant is wearing gloves and a face shield. It is the nature of a cryogenic fuel that requires the special precautions, not just because it is a form of natural gas. The whole process is very similar to fueling a diesel fueled vehicle. But, with the new diesels, there is the need to check and refill the DEF from time to time. Remember, the DEF is really ammonia and requires the special attention given when dealing with ammonia.

To shut off a natural gas fueled engine, there are no special requirements. Turn off the key as you would with a diesel truck or gasoline passenger car and an electronic solenoid shuts off the natural gas supply to the engine. There are manual overrides as with a diesel fueled vehicle. The CNG fuel can be shut off at the main fuel supply valve used with the cylinder(s) on the vehicle. With an LNG fueled system, care must be taken as the LNG tank may vent natural gas to the atmosphere if the pressure rises beyond a certain point. Special precautions must be taken to ensure that the vented natural gas does not collect in a building. Thus, there is a difference in procedures for using CNG and LNG forms of natural gas.

In short, there is nothing radically different in fueling a natural gas fueled vehicle. With a proper appreciation for the nature of natural gas, operator training, and compliance with local ordinances, problems should not be expected. It is no different than the safety requirements for fueling with diesel fuel or gasoline. Using natural gas as a vehicle fuel has an excellent safety record. Standards that determine the design and manufacture of all tanks and fueling hardware have long been established.

We use natural gas to heat our homes, to cook our food, and in many industrial processes. Yes, the pressures that deliver natural gas to our homes and businesses are lower than that which we use on a natural gas fueled vehicle but the overall safety record is excellent.

There are specific ordinances that apply to vehicle repair facilities because any escaping natural gas rises up as it is lighter than air. The costs of meeting the specific requirements must be taken as an input when planning for purchase, if the owner plans on doing service work inside his own shop. If the service work is to be provided by a dealer, independent repair shop, or leasing company, the repair shop costs may not enter the cost equation.

Transitioning drivers to a natural gas fueled vehicle is relatively easy. General safety precautions mentioned previously, ease of starting in cold weather, safety monitoring devices in the vehicle cab, and the reduced noise level should all be explained. The fact that the fuel costs less and provides the fleet with a competitive advantage also should be covered.

Basic vehicle engine maintenance is very similar to a diesel engine.

Spark plugs are changed at prescribed intervals with a spark ignited natural gas engine at times measured in hours or miles similar to resetting injector overhead clearances. Don’t forget about the costs associated with periodic reconditioned injector replacement.

Compare the maintenance required and the prescribed intervals of a diesel fueled engine with its natural gas counterpart. What you won’t find required of the natural gas engine is the need to refill the DEF tank, to cause the system to burn diesel fuel to regenerate the particulate filter, and/or get the particulate filter professionally cleaned. The lower maintenance costs favor the natural gas engine.

The bottom line is that a natural gas fueled engine can lower the measured overall costs per mile of the vehicle through the use of lower cost fuel. With modern natural gas engines, you can expect diesel-like performance, general operating costs, and maintenance costs, as well as a fuel cost differential, which makes the decision to try natural gas fueled engines that much easier.
EPA REQUIREMENTS

Any theoretical discussion about alternate fuels will have positives and negatives for each fuel under consideration. One can project future cost trends to support the adoption of a particular fuel. Theory, however, goes out the window when one realizes that any alternative fuel under consideration for an internal combustion engine must meet current EPA emissions certification and have the potential to meet future certification regulations.

The chart below shows how ever-more restrictive certification requirements were imposed through the years. For the 2007 year certification, diesel design engineers could no longer meet emission requirements by design approaches within the combustion chamber and the particulate trap after treatment was adapted. For 2010 certification requirements, diesel engine design engineers added the use of DEF downstream from the combustion chamber.

Natural gas fueled engines were able to meet the stringent 2007 requirements and the more stringent 2010 emission certification requirements without the use of any downstream emission control equipment other than a simple three-way catalyst. In fact, the natural gas fueled engines met the 2010 requirements three years early.

For 2010, the current emission standard, engines must produce no more than .01 grams of particulates for every horsepower produced per hour. The particulate traps used on the diesel engines today allow compliance. Since natural gas fueled engines burn natural gas which has far fewer carbon atoms than diesel fuel, it is much easier to meet the requirement without resorting to particulate traps.

The NOx requirement is hard to meet. The current specification is that engines must emit less than .2 grams of NOx per horsepower per hour. Natural gas fueled engines have demonstrated that they can be at .01 grams NOx, far less than that demonstrated by diesel fueled engines.

If you consider where the industry was in 1970 when emission cleaning began, you can grasp just how far it has come in reducing emissions. It has not been without cost to the consumer, but design engineers for both natural gas and diesel engines have been able to meet the requirements while at the same time offering more horsepower from the same engine displacements, adding more
performance in the way of engine responsiveness, adding new features, and at the same time increasing overall fuel economy.

Many people previously suggested that natural gas fueled engines would lose sales popularity when we reached EPA emission requirements for 2010. Their thinking was that both diesel and natural gas engines would be just as clean and the claim of natural gas engines being cleaner would simply disappear. What was overlooked in these theoretical discussions was what it would take for the diesel engine to meet the 2010 requirements.

Diesel engine particulate traps, particulate trap regeneration systems, and the injection of DEF downstream of the combustion chamber added to the initial cost and overall weight of the diesel engine installation into the truck chassis as well as the ongoing operational, maintenance, and system repair costs.

As this material is being written in 2012, some are manufacturing diesel engines that do not meet the stringent 2010 emission requirements and are allowed to be sold by the use of credits. Credits are earned because prior engine models were sold where emission characteristics were below the mandated emission requirements. In time the emission credits expired and the manufacturer is faced with the dilemma of getting current production engines into compliance, even if it means selling engines that do not compare with competitors performance and fuel economy.

As outlined, diesel fuel contains more BTUs of energy per unit of measure, can be used in engines at higher compression ratios, and can generate more power than those fueled by natural gas. The great equalizer in the theoretical discussions is the fact that the engines must be emission compliant and it is much easier and less costly to make the engines compliant when they are fueled by natural gas. Add in the fact that natural gas as a fuel is substantially less expensive than diesel and the current trend is that the cost differential between diesel fuel and natural gas is widening; one can see why many are saying and making a bet on the future with their own capital that there is a bright future for natural gas as a fuel for commercial vehicles.
Chapter 4: THE PRESENT

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TODAY’S MARKETPLACE: PUBLIC AND PRIVATE

Looking at today’s available commercial natural gas fueled vehicles might create a distorted view of what is happening in the marketplace and what is about to happen in the future. There are two very important developments in process that will change the game. First, the price of natural gas is dramatically declining. Second, new engine and OEM offerings in the marketplace will dramatically increase the choices of natural gas fueled vehicles.

It never hurts, however, to take a look at what is happening today to help understand the dramatic change that is about to occur. After a slow, some would say painfully slow, increase in the number of natural gas fueled commercial vehicles in the last decade, the industry is set for a significant increase. In the last ten years, natural gas fueled vehicles were sold predominately on an environmental basis. Regardless of the EPA standards, natural gas engines always produced cleaner emissions than diesel. The diesel was making progress, but it was much easier for natural gas engines to meet and beat the standard. Because of the relatively slow pace of sales, a number of manufacturers exited the market. John Deere, which enjoyed a following in the natural gas fueled school bus and transit bus markets, decided to discontinue its efforts. Detroit Diesel also discontinued its natural gas offerings, which left the market to Cummins Westport (the spark ignited natural gas engine joint venture between Cummins Inc. and Westport Innovation) and the Westport Innovation HPDI engine (High Pressure Direct Injection).

John Deere’s exit may have been clouded by its possible strategy to increase overall engine sales to OEMs by starting with the natural gas engine and progressing to its diesel engine line. Other than success at a few OEMs with its natural gas product, the company didn’t have an expanding market for its diesel engines to OEMs. An economic decision was made to exit the market.

Detroit Diesel had a natural gas product offering that many customers preferred. When it became part of Daimler and Freightliner, competing OEMs were not going to buy natural gas engines from a competitor. A decision was made to exit the natural gas engine market.

For both John Deere and Detroit Diesel, their emphasis was on getting a market competitive EPA certified engine to market. The emphasis seemed to be getting the product to market and not worrying about relatively low volume specialty natural gas engine sales. For the vast majority of the market, this left Cummins Westport with its spark ignited natural gas fueled line of engines, as well as any foreign competitor that wanted to enter the market. The problem for foreign natural gas engine suppliers was that they had to meet EPA emission requirements. The emission standards for these off-shore potential suppliers in their own markets were much lower than in North America. The consideration for foreign suppliers was how much money they would spend on emissions development to enter the North American market dominated by one key player, Cummins Westport.

With this background, the market continued to purchase natural gas vehicles on the basis of being cleaner. Civic groups, Clean Cities groups, and various alliances preached the gospel of clean air to the public. Diesel engine manufacturers, on the other hand, believed that the clearly visible future 2010 EPA emission requirements would make the diesel and natural gas engines equal in the marketplace from an emissions standpoint and, thus, the natural gas fueled engine marketplace would be limited in volume for specialty vehicles.

Early in the 21st century, a Freightliner truck with a natural gas engine or an Autocar or Crane Carrier refuse truck with a natural gas engine could be purchased. The vast majority of the natural gas fueled truck sales were for refuse trucks manufactured by Autocar and Crane Carrier. School and transit buses with a natural gas fueled engine also were available. Why these markets? The answer is relatively simple. Natural gas fueled engines of the right horsepower and torque characteristics were available and, most importantly, the vehicles returned daily where they could be refueled by an onsite (in most cases) natural gas fueling station. Many of the onsite refueling stations were of the timed fill variety. The vehicles were parked, a fuel line attached, and several hours later while the vehicles were parked for their normal out of service time, they were refueled. Some transit operations have more elaborate fast fill stations, but the key factor was that these operations did not have to depend upon...
commercial natural gas refueling stations. They had captive fueling stations in their backyards.

Refuse trucks were one of the first commercial vehicle groups to convert natural gas fueled trucks in large numbers. A refuse truck has a long life, and it is in the public’s eye. The older trucks, subject to less restrictive emission requirements than new ones, produced much more smoke which was clearly visible to the public. Additionally, the public was much closer to hear the noise of the diesel engine as the vehicles moved through neighborhoods and, more importantly, on city streets during the day when the public was literally standing next to them.

The quieter and much cleaner emissions (no smoke) of the natural gas fueled engine made this segment of the commercial vehicle market much more susceptible for public demands to “do something.” With taxpayer dollar grants to offset higher costs for the natural gas fueled refuse trucks, more and more entered service. For other truck applications, such as route delivery trucks, the transition to natural gas fueled vehicles was much slower. The problem was that there was only one OEM, Freightliner, who offered a natural gas fueled truck. At first it was a Freightliner truck; later, Freightliner dropped natural gas as an option but Daimler offered it on its Sterling line of trucks after acquiring the line of trucks from Ford. For the vast majority of the non-refuse truck market, you had to love natural gas fueled trucks and had to love Sterling trucks if you were going to be a purchaser.

Westport Innovation was selling its higher horsepower (450 horsepower 15 liter) engine for specialty trucking operations. In the beginning, the Westport HPDI natural gas engine promised equal horsepower and torque to a diesel engine but with much cleaner emissions. A few OEMs considered offering the Westport HPDI system (based upon the Cummins ISX diesel engine) but there were a number of obstacles to making this a success. The initial cost for the Westport powered vehicle was high and necessitated an LNG station available at the trucking company terminal or nearby, as well as along the route to guarantee steady supply of LNG.

Conversion options appeared to change a pickup truck’s gasoline engine to run on natural gas. This process included installation of one or more CNG tanks in the pickup truck’s bed or along the frame rails to complete the conversion.

There were a number of other conversion companies that enjoyed limited success. If there was a comparable diesel engine already installed, it could be replaced with a similar spec’d natural gas engine, add the new natural gas fuel system and related hardware and someone would now be the proud owner of a natural gas fueled vehicle whether it was a truck, trailer spotter, street cleaner, etc. An owner was really dedicated to make the conversion to natural gas, as it was expensive. There were numerous grants, tax credits, and other programs to make all this happen. In the end, this was the 2008 marketplace. A new natural gas fueled vehicle could be ordered from a few select OEMs or an older engine could be converted to natural gas fuel.

There were demonstration projects to promote pure electric and hybrids (diesel or natural gas powered along with a battery and electric motor) with their advantages and disadvantages. This too was a specialty market with the major advantage that it replaced, for the most part, the diesel engine. The compromise was that much weight was added in the form of batteries that took away from payload, as well as adding more complexity and costs, all in the hope of reducing emissions and lowering overall costs. OEMs began to offer these hybrids in their data books, but the costs were still higher than the diesel engine. Reliability, serviceability, and long-term costs were yet to be determined; however, customers now had options to the traditional diesel.

What the natural gas vehicle supporters sought in the marketplace was the “first responders,” those willing to invest in something new in the hopes of lowering emissions and operating costs. If the demonstration projects could be believed, there was a big reward. The thought was always that as volumes increased, costs of the vehicle would decrease and the number of public natural gas fueling stations for commercial vehicles would grow. All this implied that natural gas fueled engines could replace a large portion of the diesel engine market.
If the 2010 EPA emission standards made it a non-emissions issue as natural gas and diesel fueled vehicles would be equal on emissions, why would the commercial vehicle market move away from diesel? What would be the incentive?

There would always be a very small percentage of people who wanted something different or were promoting the advantages of a different approach. After all, wasn’t it Clessie Cummins who pioneered the diesel engine over gasoline in the 1930s? How did we move to diesel anyway?

So, the stage was set. The natural gas fueled engine suppliers continued to sell engines to refuse market suppliers, to school bus and transit bus builders, and one truck manufacturer. The next questions were how to grow the market and more importantly, how to keep it from contracting.

And then it happened! Sterling exited the truck market and took the natural gas engine options with it. What next? How can the natural gas fueled engine market expand without a flagship truck? Converting existing diesel powered trucks to a natural gas configuration was not an economically viable option.

Before it left the market, Sterling sold some Cummins Westport Inc. powered ISL G (model name for a maximum 320 horsepower/1,000 lb. ft. of torque) engines to ports on the West Coast. These natural gas powered trucks helped solve the ports’ problem.

Containers were being hauled from the ships at dock to the railhead for distribution to all parts inland. In the past, due to the prevailing freight rates, older model diesel trucks, predominantly used line haul trucks, were being used to haul the containers inland. With the older age of the trucks, less stringent original emission certification, and actual condition of the engines after many miles, one could trace the emission problem that part of the country was having to these older trucks.

How could essentially medium duty trucks with medium duty natural gas engines haul these sometimes heavy containers inland as the older heavy duty used trucks had done? The answer proved to be the traffic. The newer medium duty trucks never had to go as fast as an older line haul truck outside of the port area (higher speed takes more horsepower than the medium duty trucks could produce). Traffic flow determined what actual speeds the vehicles were traveling, and the natural gas trucks were doing just fine. With some new rules and regulations, natural gas trucks were approved. Programs were implemented to help offset the higher price of the new natural gas trucks rather than the much lower cost of the older used trucks.

The truck sales downturn into the difficult 2009 and 2010 markets was underway. With the demise of the Sterling brand of trucks, Freightliner had reentered the natural gas fueled truck market and had a near lock on the demand for new trucks at the ports. Other truck manufacturers entered the natural gas fueled truck market to expand sales in a down market.

At the same time, the commercial vehicle truck market learned a little more about diesel fueled trucks and what it was like to operate 2007 emission certified engines with their new after treatment systems. Additionally, they had a better look at what the 2010 emission certified diesel engines would be to operate with their after treatment systems and requirement to add DEF. The cost per mile of operation for a diesel escalated.

Meanwhile, commercial vehicle operators saw the cost per mile operating costs for the 2010 emission certified vehicles escalate, as the price of diesel fuel began to climb. At the same time, the price of a DGE (Diesel Gallon Equivalent, the energy content measured in BTUs of diesel fuel is equalized with that of natural gas) decreased. Shale oil exploration brought more natural gas and the price for natural gas fuel began to drop dramatically. The differential between the price of diesel fuel and natural gas widened. The long term trend is for the gap to widen, as the price of petroleum (diesel fuel) increases and the price of natural gas decreases.

The adoption of natural gas fueled vehicles had been slow in coming; suddenly, market forces changed the landscape:

- Natural gas powered vehicles had been used successfully in larger numbers than before.
• More OEM medium duty natural gas engine truck availability resulted from successful port use.
• The natural gas fueled refuse trucks were doing just fine in service and were taking advantage of the lower price of natural gas compared with diesel. In the case of the refuse market, it paid to be an early adopter.
• The price of diesel fuel escalated to record levels at the same time the price of natural gas dropped. The long term trend was for diesel to keep escalating and for natural gas to remain near record lows.
• The real costs of operating 2010 emission certified diesel engines (the current standard) with particulate traps, DEF requirements, and professional particulate trap cleaning became more known.
• The actual lower costs of operating natural gas fueled trucks with less costly fuel and simpler three-way catalyst after treatment systems were reinforced when cost comparisons were done with diesel.

All of the above factors caused a number of truck manufacturers, natural gas engine suppliers, and natural gas fuel suppliers to make some big bets on the future, which will be reviewed in the next section. The natural gas fueled commercial vehicle market was poised to move from a specialty vehicle segment to more mainstream. Many thought that with the 2010 EPA emission standards, natural gas fueled truck sales would stall; this didn’t happen.

In today’s marketplace, companies are trying to differentiate from the competition. One way to differentiate is cost or price.

ACT believes that today’s natural gas fueled commercial vehicle offerings by the OEMs reflect a growing awareness that natural gas emerges as the lower cost alternative for those companies who want to differentiate on cost. Engine emission characteristics, for the vast majority of users, do not sell new commercial vehicles. The perception is that each new emission standard hurdle adds cost, may impact performance, and lowers overall fuel economy.
WHAT ARE THE OEMs OFFERING?

Natural gas fueled engine offerings at OEMs are rapidly expanding. It is very difficult to provide a current list without updating it weekly. As you look at industry sites that attempt to provide the latest offerings, you sometimes have to learn a new language: SING, PING, and DING. These terms define the type of engine being offered.

- **SING**: Spark Ignited Natural Gas.
- **PING**: Pilot Injection Natural Gas
- **DING**: Direct Injection Natural Gas.

The problem with looking at today’s offerings is that they do not include the major transition to natural gas fueled heavy duty trucks that is coming; they only include today’s available medium duty and specialty offerings.

One can get an idea of the breadth of today’s offerings by reviewing the online site for Cummins Westport natural gas engines (http://www.cumminswestport.com). The site currently lists (as of this writing) 42 OEM applications for the ISL G natural gas engine, which has a maximum rating of 320 horsepower and 1,000 lb. ft. of torque. The applications range from trailer spotters (Kalmar, Capacity, and Autocar) to short-haul tractors (Freightliner, Kenworth, Peterbilt, and Volvo). One can also order street sweepers from Elgin. Included in the list of applications are dump trucks, mixers, school buses, shuttle buses, and transit buses. The point is all the truck OEMs, except Western Star, have truck and tractor offerings. There is competition among the OEMs. Early in the 21st century, there may have been just one OEM for each application and the vehicle was priced accordingly. That has all changed.

Recently, Navistar joined the ranks of those OEMs offering a natural gas option, and this is a significant announcement. Navistar will be currently approaching the natural gas commercial truck market from two angles. First, the company has announced that it will be using the Cummins Westport ISL G natural gas engine. Second, Navistar has announced that it will design, develop, manufacture and market its own 13 liter design natural gas engine. With the exception of Western Star, all North American truck OEMs are competing in the natural gas marketplace.

Some manufacturers have been in the North American natural gas engine marketplace for some time, such as Autocar, Crane Carrier, and Mack. At the beginning of the 21st century, when natural gas engines were being promoted as cleaner and more emission friendly, it was a real struggle to get OEMs to offer natural gas engines because the market demand did not exist. OEMs now are promoting themselves as the leader in the movement to natural gas fueled trucks.

The game changer is that, to date, most truck offerings have been medium duty with the exception of the Westport HPDI line haul engine. Cummins Westport has announced that it will release an 11.9 liter (called a 12 liter) ISX 12 G engine of 400 horsepower with 1450 lb. ft. of torque for 2013 production. Expected emissions certification level is slated to be 0.2 g/bhp-hr NOx and 0.01 g/bhp-hr PM. There will be a compression brake option on this engine. The engine is the same whether the vehicle uses CNG or LNG fuel. It will be a SING type engine with a simple three way catalyst.

Cummins, separate from the Cummins Westport joint venture and separate from the Westport HPDI engine, has announced it will produce a 15 liter ISX G (SING) version of its popular diesel engine in 2014. Horsepower and torque projections were not announced; with increased displacement comes the opportunity for higher horsepower and torque ratings.

So, the industry is ready to move from a concentration of medium duty natural gas offerings to the heavy duty arena with engine offerings from Navistar, Cummins Westport, Cummins, and Volvo. These new offerings will compliment the Westport HPDI engine offering available today. In short, natural gas engine suppliers as well as OEMs are betting that truck and tractor purchasers want natural gas fueled options to supplement traditional diesels.

Fuel suppliers are leading some of the industry expansion. Clean Energy Fuels has committed to bring more fueling stations for truckers on line in 2012 with more to follow. Shell recently announced
that it would sell LNG to heavy road transport customers in the United States through TravelCenters of America with a planned expansion of more than 200 LNG fueling lanes at about 100 sites in 2013. If they and their competitors did not believe the natural gas fueled commercial vehicle market was rapidly expanding, they would not be risking their capital. It was an agonizingly slow start at the beginning of the 21st century to get end customers, OEMs, and fuels station providers into the natural gas fueled commercial vehicle market. Today, that race is on to be first with the most customer requested options.

Truck OEMs are perceptive. When they plan to introduce new, higher GVW models fueled by natural gas into the marketplace, they do so because they are listening to their customers. In the 1980s and 90s during the last oil price spikes, many of their diesel customers were forced out of business. With the decline in the number of customers, the price pressure on the OEMs increased as fewer suppliers (the OEMs) were chasing a smaller number of customers. What seemed to save a number of commercial truck operators was a fuel surcharge that they could negotiate with their customers to pass on their higher costs for fuel. The surcharge took the sting from oscillating fuel costs. If there was stable, long term fuel pricing, then the fuel surcharge would disappear. But, did the fuel surcharge just cover the actual increased fuel costs or was it a way to add on a little more in the way of additional profit potential?

Many of the large carriers wished the fuel surcharge would disappear as it added another item of complexity into freight movement pricing. If there is another fuel such as natural gas, which has the prospect for long term stable pricing while at the same time being priced below today's diesel fuel prices, then freight customers are all for it. It takes away one more negotiated piece of the price. For a carrier, non-surcharge pricing would put additional pressure on costs and, in turn, profits. If you are a large, progressive carrier that has an aggressive cost containment management, you might be all for a domestically sourced, politically stable source of natural gas to fuel commercial vehicles.

If all the above is true, what other natural gas fueled engine suppliers might enter the North American commercial vehicle market? What about PACCAR and their entry into the North American diesel engine market in the last few years? Will they come forward and produce a spark ignited and/or HPDI version of their current diesel offering? What about Detroit Diesel? Will they reenter the market for natural gas fueled engines? What about Navistar? Will they continue to use Cummins Westport natural gas engines to meet customer demands or will they, in time, switch to using only their own designs after they gain entry to the market? Will Navistar adopt the new for 2014 ISX G natural gas engine from Cummins?

One can answer some of the above questions if he or she knows what percent of the commercial vehicle market will be fueled by natural gas in the future, say the next five years. If the market for natural gas fueled commercial vehicles expands rapidly in the years ahead, then, there may be enough volume for Mack, PACCAR, and Daimler Chrysler to design, develop, manufacture, and market their own natural gas fueled engines, whether they be spark ignition or compression ignition versions, and offer them in the North American commercial vehicle market. In the meantime, it would appear that the Cummins Westport, Cummins Inc., Westport, Navistar and Volvos of the world can supply the market as they ramp up to supply the demand. If the demand for natural gas fueled engines is not a game changer, then the above OEMs can source their natural gas engines from the existing independents and/or announced in house suppliers.

The question remains: how fast will the commercial vehicle industry adopt natural gas as a fuel of choice? Is the current activity to offer more natural gas fueled trucks and tractors, as well as bring on higher GVW vehicles, an aberration or is it the start of a rapidly escalating trend?
FUELS OF CHOICE OUTSIDE NORTH AMERICA

Americans may think that the United States is on the forefront of a decision worldwide to adopt natural gas as a fuel for a portion of private and commercial vehicles. According to information from NGVAmerica, there are 120,000 natural gas vehicles on U.S. roads today, but 14.8 million worldwide. That means less than one percent are in the United States. The U.S. is 17th in the world on usage. According to the March 2012 Gas Vehicle Report, the 14.8 million vehicles in use are expected to rise at a compounded annual growth rate of 7.9%, reaching 19.9 million vehicles by 2016. In the next 10 years, they estimate that there will be more than 50 million natural gas vehicles worldwide, about 9% of the world transportation fleets.

Further, natural gas vehicles are most successful in the Middle East and Latin America where they lack a high capacity to refine oil. According to NGVAmerica, the top 5 countries on the basis of number of natural gas vehicles are:

<table>
<thead>
<tr>
<th>Country</th>
<th>Number of Vehicles</th>
<th>% Total Global NGVs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iran</td>
<td>2,859,386</td>
<td>19.31%</td>
</tr>
<tr>
<td>Pakistan</td>
<td>2,850,000</td>
<td>19.25%</td>
</tr>
<tr>
<td>Argentina</td>
<td>2,077,581</td>
<td>14.03%</td>
</tr>
<tr>
<td>Brazil</td>
<td>1,702,790</td>
<td>11.50%</td>
</tr>
<tr>
<td>India</td>
<td>1,100,376</td>
<td>7.43%</td>
</tr>
</tbody>
</table>

The United States imports more than 47% of the oil that it uses while 98% of the natural gas used in the United States was produced in North America, according to NGVAmerica.
WHAT OTHERS, BESIDES HD TRUCKS, ARE DOING WITH NATURAL GAS

Buses: School, shuttle and transit buses have used natural gas for a number of years. In the past, the emphasis was cleaner air. Cleaner air for students on school buses, cleaner air for the population in cities utilizing transit buses, and cleaner air around airports, hotels and other areas where there is a good amount of vehicle congestion was a public inspired movement.

In general, school buses don’t burn much fuel, but they do spend a good deal of time idling. With fuel price subsidies, grants and government programs, the higher cost of natural gas fueled school buses could be justified for clean air purposes in the past while any fuel price differential savings in favor of natural gas were not offset by the higher price of the new equipment.

Alternatives to diesel in school buses meant propane, gasoline, or natural gas. Early in the 21st century, John Deere (before it exited the market) and Cummins Westport served the school bus market with an alternative natural gas engine.

Most of the natural gas fueled school buses were fueled with time fill natural gas refueling systems. Parked at night, the buses were refueled and ready to go in the morning. Without being low on fuel, they were ready for service in the afternoon to return students home. After returning from the afternoon runs, the school buses were parked for refueling. If needed, because of route requirements, school buses could be refueled between the morning and afternoon runs.

Where cities were concerned about air pollution around airports and hotel complexes, many van-type shuttle buses were ordered with a factory natural gas option, when available, or converted locally. For routes with demand for a larger number of passengers, full size commercial buses with natural gas engines were used. These shuttle buses reduced overall airport pollution because of overall reduced emissions. Many of these shuttle buses used nearby commercial refueling stations and/or installed their own refueling station. The type of station was a function of the hours of service required and amount of fuel used.

As with the school buses, the emphasis on shuttle buses at the beginning of the 21st century was the cleaner air. You had to want the cleaner air as there were many incremental costs: the natural gas fueled vehicle, the higher cost maintenance facility, and the fueling station or dependency on a nearby commercial fueling station.

With public transit buses, two factors were at play: the contribution to cleaner air and the possibility of lower fuel costs for the agency. Large metropolitan cities had clean air problems and large transit buses were quite visible to the public, making them targets for clean air efforts. Transit agencies generally are not operated to make a profit, but rather to serve the public. Transit agencies, commissions, boards, etc. all set the policies for the transit agencies with actual costs of operation far down on the priority list. With that in mind, clean air was the motivating factor to make natural gas the primary fuel for a number of fleets with Detroit Diesel, John Deere, and Cummins Westport all vying for orders.

Due to the duty cycle of transit buses, in-house fueling stations were adopted, many being fast fill. Transit buses carry passengers all hours of the day with heavy demand during rush hours. Slow fill systems were not practical. On the West Coast, some agencies tried LNG; those on the East Coast used CNG. With a little bus structure modification, an appropriate number of CNG tanks could be installed on top of the buses. Besides the advantages of cleaner air, the buses were much quieter in operation, a bonus in large cities.

According to the American Public Transit Association, nearly one fifth of all transit buses in 2011 used natural gas. Collectively, they are the largest users of natural gas for vehicles.

One of the earlier lessons transit agencies learned was the practice of natural gas suppliers in the colder climates substituting propane into the natural gas supply lines during times of peak demand. Natural gas engine failures were traced to the presence of propane in the fuel. Natural gas fuel requirements limit the amount of trace amounts of propane supplied to the engine fuel systems.
Think of what happens on a cold East Coast morning. As home furnaces start to raise home temperatures, as those who cook with natural gas prepare breakfast, as those industries that use natural gas in production processes begin work, the demand for natural gas increases. Natural gas line pressures decrease and to maintain pressure, the natural gas supply utilities were substituting propane into the supply lines. In those operations where natural gas is used for heating, customers rarely knew the difference as the natural gas and propane combination was used to generate heat.

To prevent natural gas engine failures, the simple solution was for natural gas transit bus operators to know, in cooperation with the gas suppliers, when propane was being added to the lines. Natural gas compression and storage was suspended until the propane was no longer being used to supplement the natural gas.

In summary, for school, shuttle and transit buses, the initial thrust for purchase was cleaner air. Interested parties could measure the difference in grams per brake horsepower per hour (g/bhp-hr) of particulates and NOx between diesel and natural gas emissions by looking at the actual engine certification information. The additional expense for the buses, for the fueling infrastructure, and for maintenance shop conversions was justified on the basis of reduced emissions. Many grants and federal or state incentive programs provided funding to offset the incremental costs. The actual differential between the cost of diesel and natural gas was nowhere near today’s rate.

The early adopters were pursuing lower emissions. They accomplished that goal. In the process of introducing natural gas into fleets, they quickly understood the advantages and limitations of running natural gas fueled buses. Today, they are reaping the benefits of the lessons learned as the price differential between diesel and natural gas reinforces the early decisions to go with natural gas. As they began to see how diesel engines would meet the 2007 and 2010 emission standards with DEF, particulate traps, and particulate trap regeneration, it was clear that natural gas as a fuel with a simple three way catalyst was a more practical solution given that many of the bus applications spent a good deal of time idling where they did not generate enough exhaust heat and flow to keep diesel powered units from constantly regenerating by burning diesel fuel.

Today, these early adopters appear to be smart, forward thinking and earning the rewards of lower cost of operation with natural gas powered buses while still maintaining lower exhaust emissions.

**Passenger Cars:** Outside North America, many more passenger cars are designed to use natural gas as originally constructed or converted shortly after manufacture. Outside North America, CNG is much more readily available and priced under the cost of gasoline. Many OEMs offer natural gas powered vehicles outside North America that they currently do not offer in North America.

In the North American market, natural gas fuel availability and the premium price for natural gas fueled vehicles restricts demand. When the price differential between natural gas and gasoline was small, it wasn’t worth trying to economize on fuel cost while dealing with limited natural gas vehicle range and refueling capability. Besides, the average passenger car in North America travels approximately 12,000 miles a year. It was hard to justify the incremental costs for a natural gas fueled vehicle with the relatively few miles driven each year.

As the fuel price differential widened in recent months and as the prospect of more natural gas fueling stations increased, the economics of operating a natural gas fueled automobile became more attractive. For those who did want a natural gas fueled vehicle, Honda had an answer that really made sense.

Honda offers a natural gas fueled Civic passenger car. It looks the same as a standard Civic. It has a CNG tank in the trunk that takes up some space, but other than that one would be hard pressed to tell any difference in looks, the way it operates, or how it sounds. The big difference is the ability to fuel the vehicle at home.

If your home has a supply of natural gas, you can secure a home fueling device. The device, about the size of an overgrown pay telephone, mounts in your garage or carport and takes the very low pressure natural gas into your house that you use for heating and cooking and boosts the pressure.
up to 3,600 psi as your car is parked for the evening. In an average evening, about 8 hours, it can refill the CNG tank in the trunk of the Honda Civic. It boosts the pressure at the rate of one GGE (gasoline gallon equivalent) per hour at 3,600 psi. If you can achieve 25 - 30 mpg on the natural gas fuel, you have an operating range in the neighborhood of 200 plus miles. With that kind of range, it easily works for a good number of people to get to work, get to the mall, get to a friend’s house, etc. If you need more range for a longer trip, then you need to consult your list of public fueling stations and make certain you can obtain natural gas fuel where and when you need it. For many people, the natural gas fuel limitations are well within the limits of what they plan to do with the vehicle.

With the choice of natural gas fuel comes the convenience of fueling at home for a price substantially below that of gasoline and/or diesel fuel. It also includes cleaner air and, in some states and localities, the use of HOV (High Occupancy Vehicle) lanes with only one person.

**Pickup Trucks:** There have been CNG options for pickup trucks in the past and a number of trucks were converted to CNG after delivery of a traditional gasoline fueled pickup truck. A CNG tank was usually placed in the truck bed behind the cab, costing loss of hauling capacity.

CNG is used rather than LNG because the latter system does not have the pressure to drive the system without an auxiliary drive to maintain pressure and there are (today) fewer LNG stations than CNG. Some systems were designed to run on either gasoline or CNG. The thought was that one could run on the lower cost CNG fuel but have the backup of gasoline if one ran out of CNG.

Now GM, Chrysler, and Ford have all announced the availability of dual fuel CNG/gasoline fueled pickup trucks. These will be factory installed systems available at local dealerships. Some of these units are becoming available as this is being written. The dual fuel is meant to imply that the vehicles will run on CNG or gasoline with the ability to switch seamlessly from one fuel to the other. The operator can run on the less costly CNG maintaining the gasoline in reserve. The combination of CNG and gasoline provides for much more vehicle range, but pickup truck users have always had the option to add more gasoline fuel tank capacity. Full time RVers have used extra gasoline capacity systems to get extended range when hauling fifth wheel RVs.

CNG fueled pickup trucks are not new. What is new is that the major pickup truck OEMs recognize the longer term trend for much less expensive natural gas and want to be ready with product to capitalize on the market. Natural gas fueled pickup trucks are no longer a specially market to be reserved for fuel conversion companies but rather mainstream pickup trucks destined for stocking on dealer lots.

Natural gas fueled vehicles, whether they are school buses, shuttle buses, transit buses, cars, or pickup trucks have been around for years. The technology is not new. Converting a gasoline engine to natural gas is a relatively straight forward conversion. Converting a diesel to a spark ignited natural gas engine is a little more difficult, but spark ignited natural gas medium and heavy duty engines have been in the marketplace for some time. What is new is the number of OEMs willing to offer the natural gas fueled vehicle option.

ACT is predicting that more and more vehicles will be fueled by natural gas, particularly medium and heavy duty commercial vehicles. This prediction is founded on the belief that widening price differential between diesel fuel and natural gas is here to stay and not a short term aberration. If OEMs did not believe this, they would not be absorbing the cost of bringing new models to market with the expectation that they could recover those costs with an appropriate volume of sales.

Those early adopters in North America who made the transition to natural gas on the primary basis of lower emissions are now reaping the benefits of lower fuel costs in addition to the lower emissions. It will be interesting to see how many more natural gas fueled vehicles become available in the months ahead in North America. For those outside North America, natural gas fueled vehicles, particularly automobiles, are a way of life, a less expensive fuel than either diesel or gasoline. Outside North America, it is not uncommon to pull a vehicle into a fueling station and find three fuels available: natural gas, gasoline, and diesel.
RECENT INDUSTRY ANNOUNCEMENTS

Elsewhere in this document reference is made to what a particular OEM in the medium and heavy duty truck market may be doing today with natural gas as a fuel. Individual OEM comments mask the fact OEMs as a whole are doing more collectively to promote natural gas as a fuel for commercial vehicles. To understand the magnitude of the change, we need to take a quick look at the past and, then, look at what is coming short term in the future.

At the start of the 21st century, Westport Innovation announced the promotion of its HPDI system for a heavy duty truck engine. Shortly thereafter, Cummins Inc. and Westport Innovation announced their joint venture, Cummins Westport, (CWI) to focus on the spark ignited natural gas fueled engine market for medium duty trucks and buses.

John Deere was a competitor that offered a well respected spark ignited natural gas fueled engine that was used extensively in school and transit buses. For whatever reason, John Deere exited the market.

Detroit Diesel had a natural gas fueled engine option. It was a recognized competitor in the transit bus market. For whatever reason, Detroit Diesel exited the marketplace.

Offshore vehicle and engine manufacturers looked at the North American market, but the investment required to develop engines that met the emission standards for North America in relation to expected sales was a tough decision.

Just having a natural gas fueled engine that met the strict North American emission standards wasn’t enough. One needed an OEM willing to install the natural gas fueled engine and partner for sales. All this was happening at a time of industry consolidation. OEMs did not have the funds to engineer every available natural gas fueled option. Rather, they had to pick a partner and pursue sales. As a result, the number of natural gas fueled engine suppliers dwindled. Those that remained had to constantly balance niche market sales with engine development, manufacturing and sales costs.

The marketplace was one of selling cleaner air. The emissions from a natural gas fueled engine were substantially less than those from a diesel engine. If you wanted clean air, you purchased natural gas fueled engines for your vehicles, solved the fueling availability issues for your location, and made the investments required to get your repair and maintenance facilities into compliance. Engine sales were relatively stable in a niche market.

In 2006, Cummins Westport announced that it would produce a 320 horsepower engine with 1,000 lb. ft. of torque that met the tough 2007 emission standards with a simple 3-way after treatment catalyst. At that time, the market was getting its first look at what it would take to meet 2007 emission standards with a diesel.

2007 was a watershed year for the diesel. No longer would emission standards be met within the combustion chamber but rather with a new particulate filter in the exhaust stream. The trucking industry learned new terms such as particulate filter, regeneration and professional filter cleaning. There were higher costs for the engine and maintenance, and fuel economy may have taken a hit. And in just three years, the 2010 emission standards would need to be met.

Well into the 2008-2009 timeframe, medium and heavy duty vehicle users learned of two divergent paths to meet 2010 emissions for diesels. One path was to use more EGR (exhaust gas recirculation) to reduce combustion temperatures and emissions; the other was to use DEF, to treat the exhaust downstream of the combustion chamber. In the end, all North American truck OEMs except one chose the DEF approach while one chose to manufacture its own engines using the additional EGR approach. Each manufacturer touted the advantages of its approach while at the same time outlining the disadvantages of a competitor’s approach.

Now it became clear that the Cummins Westport Inc. natural gas approach was a simple way to cleaner emissions while at the same time increasing the maximum horsepower available, but it was still a medium duty horsepower application.
The above outlines the past as we approach 2012. The price of natural gas has dropped dramatically and it appears that it will remain low for some time to come. The price of petroleum has escalated for gasoline and diesel users. In short order, OEMs and engine manufacturers made their new bets on the future. Here is how it currently stacks up with new natural gas fueled product introductions:

**Navistar:** Navistar announced the planned development of its own 13 liter natural gas engine. Reportedly, it will run on a combination of diesel and natural gas with the diesel being used to pilot the ignition. Horsepower and torque ratings and the engine option release dates have not been publicly announced. The new natural gas engine is aimed at the heavy duty truck market segment. It will be used exclusively by Navistar for its own truck production and will use LNG as a fuel.

At the same time Navistar announced the availability of the Cummins Westport ISL G, an 8.9 liter spark ignited natural gas engine, aimed at the medium duty truck market. The engine is certified to 2010 emission standards (the most current standard) and in full production and utilized by competitors of Navistar. As the engine is designed to be used with either CNG or LNG fuel supplies, both options will be available.

In summary, Navistar has announced its plans to cover the medium and heavy duty segments of the truck market with a natural gas engine offering. It is investing in a market where it anticipates increased natural gas fueled medium and heavy duty truck purchases.

**Clean Energy Fuels, Inc.:** In conjunction with these engine offering announcements, Navistar outlined a joint marketing effort with Clean Energy Fuels, a natural gas fuel supplier, to insure enhanced natural gas fuel availability. Special marketing programs for natural gas fueled truck purchasers are being discussed. In the next year, Clean Energy plans to have primarily LNG fueling facilities available along major truck traffic corridors as shown below:

Navistar and Clean Energy Fuels have partnered with purported programs to offset the natural gas vehicle price premium if the purchaser makes a commitment to purchaser a certain amount of natural gas fuel at Clean Energy Fuels stations at a slightly higher price than others might be paying. In short, they are offering a purchase incentive.
Cummins Inc.: Cummins announced that it will release in 2014 a new 15 liter spark ignited natural gas engine for North American trucking applications. No horsepower or torque specifications have been released at this time. The engine will be based upon the 15 liter ISX diesel engine currently in production. What is important in this announcement is that Cummins will be in competition in 2014 with Westport and its 15 liter version HPDI natural gas version of the Cummins ISX diesel engine. Westport currently builds a natural gas engine that is based upon the Cummins ISX diesel engine platform.

Cummins Westport Inc. (CWI): CWI currently supplies a predominantly medium duty use 8.9 liter engine of 320 horsepower (the ISL G). They recently announced that they were increasing horsepower and torque availability with the early 2013 availability of an 11.9 liter (called the ISX 12 G) engine. The engine is based upon the 11.9 liter ISX Cummins diesel platform.

A maximum of 400 horsepower with 1,450 lb. ft. of torque was announced with an engine brake as an option. The engine is the same spark ignited engine whether the fuel supply system is CNG or LNG. The engine is currently undergoing Beta testing. It was shown installed in a number of truck OEMs at the 2012 Mid-America Trucking Show. The heavy duty horsepower rating put this offering squarely in the regional haul marketplace whereas the ISL G was clearly a medium duty engine.

The new ISX G will be available for use with automatic and manual transmissions. This is a change for CWI as the ISL G was used almost exclusively with automatic transmissions. An automatic transmission was used to improve the vehicle’s ability to start on a grade.

This announcement of the new engine outlines that CWI believes an increasing number of truck operators requiring more horsepower and torque than it offered before are interested in natural gas fueled engines.

In summary, at the beginning of the 21st century, natural gas fueled engines were available predominantly for the medium duty truck market and marketed as a cleaner alternative to diesel. Comparisons were made on the difference in overall pollution compared with diesel. There was fuel cost advantage in favor of natural gas, but the vehicles were more expensive, fueling stations were problematic unless you installed your own fueling stations, and the required upgrades to maintenance and repair facilities could be expensive. OEMs offered natural gas engine options but they tended to be expensive. Purchasers were counting on grants, rebates and other programs to offset the higher purchase price of the natural gas fueled vehicles.

With the dramatic drop in the price of natural gas and the prospects for the large favorable price differential with diesel fuel to remain for some time, new OEMs were drawn into the market. Existing engine suppliers increased horsepower offerings and announced availability dates and new higher horsepower models for future release. Plans for building new natural gas fueling stations within the next 12 months were announced. In short, a number of prominent OEMs, natural gas engine suppliers, and fuel suppliers have made a large bet that the natural gas fueled commercial vehicle market is set for expansion.
NORTH AMERICAN FUEL PRICES

The price differential between a DGE of natural gas and diesel fuel at the time of this writing is approximately $1.50. Given the amount of natural gas being found and stored, we can anticipate that the differential will exist for some time. Reportedly, producers are running out of storage space to store the captured natural gas and wells are being capped. In a May 3, 2012 Wall Street Journal article, it was reported that producers were holding natural gas off the market in hopes it would spark a rise in prices.

You can’t change the basic laws of supply and demand. You can attempt to make minor adjustments in price, but the probability that the price of natural gas can be manipulated to bring it back to near its peak is remote. Since the amount of gas is much larger than what was first anticipated, it is now believed that we have a 100-year supply for all users.

Whether one is producing a DGE of natural gas or a gallon of diesel fuel, there are individual elements to that total cost. Collecting, refining, transportation, and fueling station costs, as well as other costs, add to the per gallon price. Even if the price of the natural gas were to rise, it would have to climb a significant amount before it would negatively impact the DGE price of natural gas.

If the above is true and there is a long-term prospect for a big differential in the DGE price of natural gas versus diesel, then there are some questions that follow:

- How long is the favorable differential going to last? Should I adopt natural gas for all or part of my commercial vehicle fleet or will the favorable price differential disappear just about the time that I get my vehicles delivered?
- Will there be a major shift in the current number of natural gas vehicles and the amount of natural gas that these vehicles use? In short, will the current advantage in natural gas pricing compared with alternatives shift such that the current advantage for commercial vehicles is negated?
- Are there any other factors that can adversely impact the current price differential that would negate the current advantage of using natural gas in commercial vehicles?

The above questions generalize what is being asked in the industry. As you attempt to answer the above generalized questions, one can come to the conclusion that (A.) I’m making the smart move to convert future purchases of commercial vehicles to natural gas fuel or (B.) I’m smarter in doing nothing about moving to natural gas as a fuel for commercial vehicles as the current differential will disappear in the near future because it is an aberration in long term pricing. It would be a mistake to move toward adopting natural gas as a fuel for commercial vehicles.

Some alternative scenarios could be:

- Oil producing nations (the Middle East) sense the threat of the U having a long term glut of natural gas and, therefore, substantially drop the price of crude oil accordingly. The answer is that it is a world market for crude oil. Why would oil producers drop the world price for oil when it is just the United States that has a glut of natural gas? What about the demand in Japan where they have neither an in-country supply of natural gas and/or oil? Also, China has a large demand for oil. Just because the United States’ need for oil might change, will the oil producing nations drop their prices for oil to China?
- Other work continues on alternatives to natural gas and diesel fuel. What happens if there is a breakthrough? Most experts believe that the long term trend toward a price differential favoring the price of natural gas is real. Estimates of the amount of natural gas and/or petroleum in the ground are just that, estimates. Many people with the same access to estimates of the amount of energy in the ground have come to the conclusion that we have an abundance of natural gas and they are making bets with their own money that the long term trend is favorable. Whether you are a fuel supplier, user, or a supplier of vehicles that will use natural gas as a fuel in light, medium duty or heavy duty trucks, bets are being made with private capital that the supply of natural gas is real.
Of course there are no guarantees. A natural inclination would be to do nothing. You don’t have to change to natural gas fueled vehicles tomorrow or the next day. Why not just wait and see how it all unfolds? Therein is the problem. If the long term trend differential favoring natural gas pricing compared with diesel is true and some fleet managers take no actions but competitors do, what then? Has the fleet manager who does not adopt natural gas as a fuel given this competitor who does adopt the technology an edge in the marketplace?
IMPAKT OF PENDING LEGISLATION

As one considers whether natural gas might be a viable option for increased usage in commercial vehicles, one might ask if there are any “Show Stoppers” in pending legislation. Three pieces of legislation come to mind for consideration:

- New Heavy Truck Tractor Stopping Rule
- Engine/Vehicle Emissions
- Fuel Economy Standards

Truck Stopping Rule: The Federal Motor Vehicle Safety Standard (FMVSS) 121 mandates that stopping distances for truck tractors traveling at 60 mph be reduced from today’s maximum of 355 feet to 250 feet, a significant 30% reduction. By comparison, a passenger car can stop in about 140 feet from 60 mph.

There are two phases. The first is in place as of August 1, 2011 and the second phase by August of 2013. The requirements are shown below.

Does the typical increased weight of the heavier natural gas tanks individually impact the requirements? Not at all because it is the GVWR, Gross Vehicle Weight Rating, that is the target weight. The natural gas tanks add some incremental weight, but it is the total weight of the loaded vehicle that must meet the standard. The natural gas tanks are but one of many elements that make up the sum total weight of the vehicle. Meeting the standard requires meeting two defined elements. First, the vehicle must meet the brake dynamometer certification and second, a full vehicle stopping distance test including fade and recovery requirements from 60 MPH.

A vehicle’s ability to stop is a function of the total tractor/trailer weight, total brake system design, brake size on the steer axle (traditionally the axle with the least amount of braking), heat rejection, drum size or rotor size, and a host of other factors. Note that the new law is not a mandate to use disc brakes.

In summary, the natural gas tank weight, whether CNG or LNG, is just another element in the overall construction of the tractor and its weight and does not, by themselves, have a direct bearing on the new braking legislation.

New Emission Laws: For 2014-2018, new engine and vehicle emission laws take effect. The new laws are not a further refinement of the current NOx and particulate standards but rather a movement to regulate other engine/vehicle emissions. The emission and fuel economy standards are being introduced together but for simplicity, let’s review the individual elements.

The EPA has developed new GHG (Green House Gas) emission standards under the Clean Air Act. Under the new regulations, CO₂ (carbon dioxide), N₂O (nitrous oxide), and CH₄ (methane or natural gas) are to be regulated. The new standards will cover all on-road vehicles of GVW equal to or greater than 8,500 pounds.

At the same time, the NHTSA (National Highway Traffic Safety Administration) is proposing fuel efficiency standards under the authority of the 2007 EISA (Energy Independence and Security Act). The combined standards (EPA and NHTSA) are applicable to three categories of vehicles: combination tractors, heavy duty pickups and vans, and vocational vehicles. Each separate category has different CO₂ and fuel consumption standards.

The concentration seems to be reducing the CO₂ over the 4-year period while at the same time improving overall vehicle fuel economy. N₂O and

<table>
<thead>
<tr>
<th>Phase</th>
<th>Axle Configuration</th>
<th>GVWR Pounds</th>
<th>New Requirement</th>
<th>Compliance Date</th>
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<tbody>
<tr>
<td>Phase 1</td>
<td>Standard 6X4</td>
<td>Below 59,000</td>
<td>250 Feet</td>
<td>August 2011</td>
</tr>
<tr>
<td>Phase 2</td>
<td>6X4 Severe Service</td>
<td>59,600-70,000</td>
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<td>6X4 Severe Service</td>
<td>Above 70,000</td>
<td>310 Feet</td>
<td>August 2013</td>
</tr>
<tr>
<td>Phase 2</td>
<td>All 4X2 Heavy Tractors</td>
<td>All</td>
<td>250 Feet</td>
<td>August 2013</td>
</tr>
</tbody>
</table>

CH$_4$ are being controlled to cap these emissions at current levels, preventing emission increase as steps are being taken to reduce CO$_2$ and improve overall vehicle fuel economy.

Recognizing that the vehicles covered differ as to whether they are carrying payloads or passengers, two types of measurements have been established:

- Grams CO$_2$ per ton mile (and gallon of fuel per 1,000 ton-mile) for vocational vehicles and combination tractors and
- Payload-dependent gram CO$_2$ per mile (and gallon of fuel per 100-mile) standard for pickups and vans.

To make the new legislation even more interesting, nine subcategories were established based upon weight class, cab type and roof height for combination tractors. For vocational trucks, the segment is divided into three subcategories: Light Heavy (Class 2b-5), Medium Heavy (Class 6-7), and Heavy Heavy (Class 8). The breakdown can be seen in the following charts.

### 2017 Combination Tractor Standards

**EPA Emission Standards**

<table>
<thead>
<tr>
<th></th>
<th>Low Roof</th>
<th>Mid Roof</th>
<th>High Roof</th>
</tr>
</thead>
<tbody>
<tr>
<td>Day Cab Class 7</td>
<td>103</td>
<td>103</td>
<td>116</td>
</tr>
<tr>
<td>Day Cab Class 8</td>
<td>78</td>
<td>78</td>
<td>78</td>
</tr>
<tr>
<td>Sleeper Cab Class 8</td>
<td>64</td>
<td>69</td>
<td>71</td>
</tr>
</tbody>
</table>

Source: EPA Website

### 2017 Combination Tractor Standards

**NHTSA Fuel Consumption Standards**

<table>
<thead>
<tr>
<th></th>
<th>Low Roof</th>
<th>Mid Roof</th>
<th>High Roof</th>
</tr>
</thead>
<tbody>
<tr>
<td>Day Cab Class 7</td>
<td>10.1</td>
<td>10.1</td>
<td>11.4</td>
</tr>
<tr>
<td>Day Cab Class 8</td>
<td>7.7</td>
<td>7.7</td>
<td>8.5</td>
</tr>
<tr>
<td>Sleeper Cab Class 8</td>
<td>6.3</td>
<td>6.8</td>
<td>7.0</td>
</tr>
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</table>

Source: EPA Website
Chapter 4: THE PRESENT

<table>
<thead>
<tr>
<th>2017 Vocational Vehicle Standards</th>
<th>EPA Full Useful Life Emissions Standards (grams CO₂/ton mile)</th>
<th>NHTSA Fuel Consumption Standards (gallons/1,000 ton-mile)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light Heavy</td>
<td>344</td>
<td>33.8</td>
</tr>
<tr>
<td>Class 3-5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Medium Heavy</td>
<td>204</td>
<td>20</td>
</tr>
<tr>
<td>Class 6-7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heavy Heavy</td>
<td>107</td>
<td>10.5</td>
</tr>
<tr>
<td>Class 8</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: EPA Website

Similarly, we can review the vocational vehicle standards shown above:

Realizing that air conditioning systems contribute to GHGs, the standard proposes limiting HFC (Hydrofluorcarbons - the refrigerant in modern air conditioning systems) loss to no more than 1.5% of the refrigerant total capacity per year.

If the above is not confusing enough, manufacturers are being allowed different options as to how they meet the law through phase-ins.

How does all this impact natural gas fuel engines in commercial vehicles? The good news is that there is little if any negative impact. Natural gas engine manufacturers can meet the reduced CO₂ and CH₄ standards with a little in-cylinder tweaking. They will not have to add additional aftertreatment devices. Natural gas, compared with diesel, has fewer carbons in its composition, thus it will be much easier to meet the standards. What is different for natural gas fueled engines is the CH₄ or methane.

Natural gas fueled engines installed in vehicles have a number of safety systems to insure that there is no leakage of CH₄. Even at fueling stations, great care is taken to insure that CH₄ does not escape into the atmosphere. What are the new regulations target, with regard to natural gas, is to take the next steps to insure that CH₄ doesn’t escape from the combustion chamber due to incomplete combustion. Burn the CH₄ properly in the combustion chamber and you don’t have to worry about emissions.

All of the independent and OEM aligned natural gas engine manufacturers have had enough lead time with the new legislation to make the proper changes in their current product lines to meet the 2014 standards. Similarly, their new natural gas product introductions aimed for release in 2012, 2013, and 2014 have taken the new emission standards into consideration.

What impact the new standards will have on the diesel engine suppliers is not known at this time. However, they are working on 2014-2017 product releases knowing what the new emissions standards are. They have more levers to pull, as the expression goes, in that they can tweak the actual process on combustion in the diesel combustion chamber as well as tweak all the aftertreatment systems.

For both the natural gas and diesel engine manufacturers, one thing is certain; the door has been opened for future reductions in output of the recently legislated emissions. Will we see a similar path to the NOx and particulate reductions started in 1970?

Fuel Economy Standards: The new fuel economy standards for commercial vehicles will take everyone in a new direction. Since fuel is such a
significant cost of operating a commercial vehicle, operators have always strived to reduce fuel usage. There has always been an emphasis on getting the low-hanging fruit such as reduced idling, shutting the engines off and using auxiliary power when parked, reducing vehicle speeds, forced progressive shifting, and vehicle aerodynamics to name but a few. Now, more emphasis than ever will be placed on doing what management has tried to do all along, improve fuel economy.

There are no show stoppers for natural gas fueled vehicles in the new requirements. When the new emission laws mentioned above were first considered, natural gas fueled vehicles were still a niche market, a market primarily for those wanting the least amount of internal combustion engine emissions. Natural gas fueled vehicles can meet the new standards with minimal, if any, cost increases.
OBSERVATIONS

Both diesel and natural gas engine manufacturers will be working to improve the fuel economy of their respective engine designs as well as working with OEMs on engine installations and applications. This is really not something new but the continuation of an ongoing process.

Today, a diesel engine is more fuel efficient than a comparable horsepower and torque natural gas engine. The diesel operates at a higher compression ratio and squeezes a little more power from each operating cycle. Design engineers have been working since the 1930s to improve the reliability, durability, fuel economy, and overall cost of operation of diesel engines. Natural gas fueled engines have benefited from all the diesel engine developments. In the vast majority of cases, what benefited the diesel also benefited the natural gas engine. If the percentage of natural gas fueled commercial vehicles grows, that much more in the way of engine development resources can be devoted to natural gas engine development to bring improvements to spark ignited natural gas engine technology.

Increased diesel power and performance output came at a cost as we learned more about emissions. All the components in the complete diesel exhaust system add cost and complexity both in initial cost and cost per mile. In the commercial vehicle market, cost per mile of operation is way ahead of whatever is in second place on the owner’s list of considerations.

This section attempted to take a snapshot of what we could see in the marketplace realizing that the picture was changing every day. What was driving that change was the thought that there is an abundance of natural gas available in the United States and that because of that new abundance, the price of natural gas to be used as a fuel in commercial vehicles has dropped dramatically.

Diesel fueled engines came to prominence today not for technical reasons (no, they were heavier, noisier, harder to start, they smoked, and cost more to produce) but because the provided a lower cost per mile. Natural gas fuel engines are, in ACT’s opinion, set to do what diesel engines did some 80 years ago, provide a lower cost per mile for commercial vehicles. Yes, natural gas fueled commercial vehicles have their own quirks and special needs. In the end, they have the potential to provide lower costs per mile, cleaner air, quieter performance, and solve some difficult world political questions.
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INTRODUCTION

As you have read this ACT Research document, you learned about changes in the past, how automobiles transitioned from being one third electric battery powered to predominately gasoline, how trucks (heavy and medium duty) moved to diesel fueled engines, and how steam powered locomotives, changed to diesel electric. You also reviewed why turbine engines, those heavily promoted by a number of manufacturers as being the future of commercial vehicles, failed to make the grade. You are now being asked to understand why natural gas fueled engines are poised to make major inroads into the commercial vehicle market.

We’ve provided you detail about the present day market for natural gas fueled commercial vehicles, what is being offered today and what will be offered in 2013 and 2014. Additionally, we’ve explained who the known players are and how they are approaching the marketplace, allowing appreciation for the financial “bets” these industry suppliers are making with their own capital in hopes of a financial payoff. As a point of reference, ACT has outlined what is happening outside of North America with regard to the use of natural gas fuel for internal combustion engines.

You should have an understanding of internal combustion engines and how they have evolved, how they are the same, how they are different, and what their limitations are. Different internal combustion engines are all branches of the same tree as they have many similarities. You’ve come to understand that engine design and development is the science of compromise as the perfect engine has not yet been designed and released. You now understand that CNG and LNG are two forms of the same thing, natural gas.

ACT has established the hypothesis that the commercial vehicle industry will change and accept more and more natural gas fueled vehicles in the months ahead for many economic reasons. This section will build on the basic understanding that you now have and reinforce a number of factors that are impacting this change to accept natural gas fueled commercial vehicles. Some of this basic knowledge will be reinforced to help you better understand natural gas engines for commercial vehicles.

Many excellent articles, papers and reports have been written about natural gas fuel for commercial vehicles. All of these need a date point of reference, before or after the March 2012 Mid-America Trucking Show, because numerous major announcements about new heavy duty natural gas engines, new fueling station plans and commitments as well as new OEM natural gas fueled truck offerings were made at that show. In short, announcements made in the first quarter of 2012 may be game changers because of their significance for the natural gas fueled commercial vehicle market.
Chapter 5: FACTORS IMPACTING CHANGE

AVAILABLE ALTERNATIVES TO DIESEL

The answer to the question of whether there are alternatives to diesel is a simple one. Of course there are, but each one has its advantages and disadvantages. The table above summarizes transportation fuels that have been mentioned for commercial vehicles.

In considering alternatives, we need to look at, among other things, the following:

- Technical Merits: What happens when we use the fuel in an internal combustion engine? Will the engine be more efficient? What about costs to manufacture and maintain the engine in service? What happens to reliability and durability?
- Emissions: What is the impact on overall vehicle emissions when we burn the fuel in an internal combustion engine? What is the impact on the need for aftertreatment? Moreover, what is the impact from the “well to the wheels” on total emissions? What impact, if any, on overall costs?
- Fuel Distribution System: What are the costs of an adequate fuel distribution system? Will fuel distribution be universal or limited? Will the system be compatible with what we already have or will it require large amounts of capital to develop? For comparison, the fuel distribution system today handles 55 billion gallons of diesel fuel. (SoCalGas, “Oberon Fuels to Produce Ultra-Clean Transportation Fuel Using Natural Gas Under RD&D Agreement,” by Elliot Hicks, August 31st, 2011)
- With complete analysis of A, B and C above, what will the DGE (Diesel Gallon Equivalent) costs for each alternative examined in the foreseeable future?

The answers to the above questions are not easy; things are constantly changing. When considering the above questions, however, it does appear that there may be a good number of advantages for natural gas. As food for thought, you need to be aware of two uses for natural gas other than burning in an internal combustion engine that scientists are proposing for future consideration: the Fisher-Tropsch process and DME (dimethyl ether). Both approaches use natural gas to get an alternative fuel. Whether the alternatives are viable or not, we need to review the questions posed above.

**Fisher-Tropsch Process:** The process is named for its developers from 1920s Germany, Franz Fisher and Hans Tropsch. Basically, the process converts a gas to a liquid. One can start with a

<table>
<thead>
<tr>
<th>Liquid Fuel</th>
<th>GGE</th>
<th>BTU per Gallon</th>
<th>Lb. per Gallon</th>
<th>BTU per Pound</th>
<th>Energy vs. Gasoline</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diesel #2</td>
<td>0.880</td>
<td>129,500</td>
<td>7.08</td>
<td>18,291</td>
<td>113.64%</td>
</tr>
<tr>
<td>B20 Bio-diesel</td>
<td>0.900</td>
<td>127,250</td>
<td>7.13</td>
<td>17,847</td>
<td>111.11%</td>
</tr>
<tr>
<td>B100 Biodiesel</td>
<td>0.960</td>
<td>118,300</td>
<td>7.33</td>
<td>16,139</td>
<td>104.17%</td>
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<tr>
<td>Gasoline</td>
<td>1.000</td>
<td>114,000</td>
<td>6.25</td>
<td>18,240</td>
<td>100.00%</td>
</tr>
<tr>
<td>Gasoline + 10% Ethanol</td>
<td>1.019</td>
<td>111,836</td>
<td>6.30</td>
<td>17,751</td>
<td>98.14%</td>
</tr>
<tr>
<td>LPG (Propane)</td>
<td>1.350</td>
<td>84,300</td>
<td>4.24</td>
<td>19,882</td>
<td>74.04%</td>
</tr>
<tr>
<td>Flex-fuel (Ethanol E85)</td>
<td>1.390</td>
<td>81,800</td>
<td>6.57</td>
<td>12,450</td>
<td>71.94%</td>
</tr>
<tr>
<td>Ethanol (E100)</td>
<td>1.500</td>
<td>76,100</td>
<td>6.61</td>
<td>11,513</td>
<td>66.67%</td>
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<tr>
<td>LNG</td>
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<td>75,000</td>
<td>3.75</td>
<td>20,000</td>
<td>65.10%</td>
</tr>
<tr>
<td>Methanol (M100)</td>
<td>2.010</td>
<td>56,800</td>
<td>6.63</td>
<td>8,567</td>
<td>49.75%</td>
</tr>
</tbody>
</table>

Note: GGE mean Gasoline Gallon Equivalent
solid such as coal and convert it to a gas (gasification) or with natural gas itself and convert to a liquid. Germany commercialized the process in the 1930s and used it to produce commercial vehicle and automobile fuel. Germany lacked petroleum but had the coal resources.

The process can be used where “stranded gas” is found. Stranded gas occurs when natural gas is found underground but it is in such a remote location that building a pipeline to another location for distribution is impractical. Using the Fisher-Tropsch process on site, the conversion from gas to liquid is made and the liquid can be transported to where it will be used. If natural gas is readily available (non-stranded), skip the Fisher-Tropsch process and just use the natural gas.

Today, the Fisher-Tropsch process is commercialized. It requires high capital costs, high operation and maintenance expense, and there are environmental concerns from the process. Therein rests the problem. How much energy is consumed in the Fisher-Tropsch process to convert a solid or natural gas into a liquid? With the current and projected price of natural gas, how much natural gas can you consume to make something else (synthetic diesel fuel) versus just using the natural gas as a transportation fuel?

The Fisher-Tropsch process is not some new miracle discovery. The process is almost 100 years old. The process works, but when you start to answer the questions posed above, per unit costs are not as attractive as using natural gas as a transportation fuel.

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DME (Dimethyl Ether): Ever heard of Prozone, Ice Blue, or Blue Fuel? These are all names for DME. The chemical composition of DME is CH₃OCH₃. Basically, one converts natural gas, or synthetic gas (syngas) made from a solid such as coal, into methanol. Using one or more catalysts, the methanol gets converted to DME. The process can also start with biomass. In Europe, the excess capacity of paper mills (pulp mills) has been converted to produce DME. Research began in the 1990s.

The resulting gas is stored under pressure (about 75 psi) in a metal container much like propane. It burns clean and can be substituted for diesel fuel. The diesel engine’s fuel system is modified slightly (primarily the injectors). It is not used as a spark ignited fuel but rather as a compression ignition fuel. When used as a diesel fuel substitute, it can be used without aftertreatment as the combustion is clean and meets 2010 U.S. emission standards.

The use of DME requires larger fuel tanks as the energy density is near that of propane. That implies that a truck would have to carry a significant amount of fuel on board in a pressurized tank(s) to equal the range of a vehicle utilizing diesel fuel. As fuel distribution would be limited, the initial use of DME is with fleets that return to base as part of their duty cycle.

Volvo of Europe has done work with DME and has demonstrated the results of the initial work. For 2014, Volvo is planning to offer DME fueled vehicles in the U.S. commercial vehicle market. This will be in addition to CNG and LNG fueled vehicles. By now, most U.S. truckers have heard of CNG and LNG as alternative fuels. DME will be new to the U.S. market.

When natural gas is used in the process to produce DME, it is only 65% effective. That is, one only gets 65% of the energy produced as DME as one started with in the original process. There are discussions that the process can be made more effective, but right now 65% efficiency using natural gas is a fair description.

Long term, if we could make methanol from wind or solar power, then DME could be made economically. There are pros and cons to promoting DME. Today and for the foreseeable future, DME is a much more expensive fuel than diesel and not as economically viable as natural gas. When sourced from biomass, it has the potential to be a viable alternative to diesel fuel. Fortunately, Volvo will provide the U.S. market with a chance to evaluate DME.

Alternatives to diesel are almost limitless, but not necessarily practical, and the success or failure of each hinges on cost per unit. Although, all too often someone has a new idea or resurrects an old one stating that “With government grant money for more study and some long overdue breakthroughs, ‘Unobtainium’ will revolutionize the fuel for commercial vehicles.” Engine design and development engineers are more pragmatic. They understand that even though we have studied the internal combustion engine for many, many years and looked at countless variants, the internal
Chapter 5: FACTORS IMPACTING CHANGE

combustion engine is still our best choice, even though as a broad generalization, the internal combustion engine only delivers about 1/3 the energy input as power (the crankshaft rotates), 1/3 as heat going to the radiator, and, finally, 1/3 going up the exhaust stack as heat and exhaust. Yes we do get a little more than 1/3 of the energy input back as power, perhaps in the range of 40%, but far from any great miracle of 99.9% efficiency.

As hard as the industry has worked on internal combustion engine development and assessed other approaches such as turbines, diesel fueled engines still appeared to be our best bet for the future until the abundance of natural gas evolved. The diesel bet on the future, however, came with some baggage. As the industry released its plan to meet the more restrictive 2007 and 2010 emission standards, everyone discovered that the cost of using diesel fuel had increased significantly. The costs were not limited to the cost of diesel fuel which is a commodity on the world markets, but rather the cost of the aftertreatment devices new on the truck. Added to the capital costs of aftertreatment were the ongoing costs of using the after treatment (DEF consumption) and the cost of maintaining the systems (diesel particulate filter cleaning). All of these factors raised the total fuel cost significantly.

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A natural gas fueled engine is not as efficient (all costs considered) as a diesel fueled engine. This means efficiency and not fuel cost and is simply a technical observation. A spark ignited, natural gas fueled internal combustion engine is not as efficient as a diesel fueled, compression ignition internal combustion engine. Why consider a change? Even though it is not technically equal in efficiency, the natural gas fueled engine can be made to operate close to the efficiency of the diesel at substantially less cost. The total fuel cost of natural gas is simply much less than the cost of diesel for the foreseeable future. There are a number of businesses who believe the above to be true and are willing to bet their capital to bring more natural gas engine options to the marketplace, more natural gas fueled truck options to market and to increase the availability of fueling stations for commercial vehicles. The key commitment here is the addition of more natural gas fueling stations. Now ask yourself, why are people willing to invest their capital in the future of natural gas? They do so because:

- They believe we have an abundance (a 100 year supply) of natural gas.
- The supply is in the U.S. and not imported.
- Natural gas combustion improves emissions from an internal combustion engine, less NOx and less particulates.
- Even though diesel design engineers have made great strides in reducing diesel engine noise, comparable natural gas fueled engines are quieter in operation.
- They understand the use, limitations, and safety issues of using natural gas either in the form of CNG or LNG. The risks are minimal, no worse than using gasoline or diesel fuel.
- Natural gas is a renewable energy to be obtained from refuse sites and other sources. It helps solve the problem of what to do with the methane produced from refuse sites and other locations that is harmful to the environment.

In short, there are a number of alternative fuels but natural gas fueled vehicles seem to be the best compromise we can make for the future.
VEHICLE ACQUISITION COSTS

Natural gas fueled vehicles currently cost more than comparable diesel fueled commercial vehicles. Today, natural gas fueled vehicles are in comparatively limited production except in some markets such as refuse where they are approaching 40% of new truck production. There are reasons for the higher cost as outlined below:

- Natural gas engines cost more because of their more limited production compared with diesel. Natural gas fueled test cells for engine tests, the need to have natural gas fueling in the engine production plants, and the higher cost for some components all lead to higher natural gas engine prices.

- Because of limited demand (prior to the announcement of higher horsepower availability and increased fueling sites), more could be charged for the natural gas fueled vehicles. It was a specialty, niche market.

- In locations where natural gas fueled commercial vehicles were legislated in or demanded by purchasing entities, limited OEM availability by those few OEMs offering natural gas fueled trucks could demand premium prices.

- Fuel tanks, whether CNG or LNG, cost more than conventional diesel fuel tanks. In addition, they add cost and weight to the overall vehicle. While added weight doesn't necessarily mean greater cost, it is not optimum from a productivity standpoint.

- Natural gas engine suppliers, OEMs, and all related natural gas component suppliers knew of federal incentive programs (ended in 2010) that would offset, for the purchasing party, the generally higher cost of the commercial vehicle. The commercial vehicle purchaser paid a slight premium for the new vehicle, but the incentives provided by the federal government (generally, a rebate of 80% of the premium price paid more than the price of a comparable diesel fueled vehicle) offset the lion’s share of the price differential.

- Most natural gas fueled vehicles could be ordered only with automatic transmissions which substantially increased the cost and weight of the vehicle compared with a traditional manual transmission. For a good number of the vehicles ordered, automatic transmissions were the choice, regardless of whether the vehicle was natural gas or diesel fueled. With a diesel, one had the option of ordering with a mechanical (manual) transmission. In order to offset some of the reduced torque, particularly upon starting, the advantages of an automatic transmission were used.

For the above reasons, natural gas fueled vehicles cost more in the past. As we shall see, all of the above factors are changing.

In addition to the vehicle acquisition costs, the cost of providing for a fueling structure entered into the total vehicle cost consideration. If there was a commercial natural gas fueling station nearby where the vehicles could be fueled, no incremental capital was required. If the user needed a fueling station, then there were decisions to be made about size and type, as well as future expansion plans. The cost of the fueling structure, whether owned, leased or contracted, had to be considered. Fueling stations can cost in the hundreds of thousands of dollars to over one million dollars.

The last part of the acquisition cost consideration, and probably the least understood, was vehicle disposition costs. What to do with the natural gas fueled vehicles when it came time to purchase new vehicles? Use the vehicles until it is time to scrap them? Use them for part of their normal economic life and sell them as used vehicles, and if they are to be sold as used, who would consider purchasing them? A good number of natural gas fueled vehicles were purchased for their cleaner air characteristics compared with diesel. With the exception of refuse trucks, not much thought went into disposal of the natural gas fueled vehicles.

Truck dealers weren’t enthusiastic about leasing natural gas powered vehicles. What residual value do you place on the vehicle after lease and from where will the second customer come, as it is a very specialized market? Truck dealers thought through the issue of the demand for natural gas fueled vehicles in their respective trading areas and the cost associated with trying to sell outside of their areas. It wasn’t a very clear picture as to who was going to take the risk and at what cost.
Similarly, there were certain export areas where specialty trucks, such as refuse, could be sold. Wholesalers would buy used trucks, export vehicles that still had some life remaining, and part-out truck components as repair parts or export the parts from the country. Prior to 2007 emission standard engines, this may have been a steady market. But, who wanted trucks or parted-out engines that required particulate traps? Who would want diesel engines that met the more stringent 2010 emission standards that had particulate traps and needed DEF? The used, diesel engine truck market was undergoing change. Used truck values become even more confusing when you consider the unknown market for used trucks with natural gas engines.

Given all the above unknowns, for a dealer selling a natural gas fueled vehicle, it was best to get all the profit in the beginning and not count on what might happen when the customer thought about trading for a new diesel or natural gas fueled vehicle. This decision obviously impacted the new vehicle purchase price. In short, a natural gas fueled vehicle sold for a premium. For the OEM, given the specialized nature of the vehicle, the very limited and specialized demand for the vehicle, and the limited availability for additional fueling stations in future years, it was best to factor in a premium profit margin and move on. In the end, the customer paid the price.

For the OEM, the limited demand did not dictate any radical changes in the production plants that would favorably reflect truck manufacturing costs for natural gas fueled vehicles. It was much easier to outsource natural gas fuel tank installation and plumbing, whether it is for CNG or LNG. No need to install natural gas fueling facilities in-plant. Vehicles could be started and moved relatively short distances to the brake test facilities using (in the case of CNG) small temporary tanks that provided for limited vehicle fueling. The OEMs just needed a limited amount of natural gas fueling to get the specialized natural gas fueled vehicles out the door to the fuel tank supplier or custom fabrication shop before selling the vehicle to the dealer and, in turn, to the ultimate customer.

This approach caused problems for the customer. If the natural gas engine supplier tested the engine, then, it must be OK when the total vehicle got to the customer; otherwise the natural gas engine supplier’s distribution channel would need to resolve the problems. The total vehicle set up for natural gas fueling rarely got a full vehicle test as did diesel fueled trucks. This approach added to the frustration level of the customer and to the total cost of the vehicle as problems got solved under warranty.

What can we expect in the future? If the market for natural gas fueled commercial vehicles expands as ACT believes it will, what happens to vehicle costs? The price of diesel powered vehicles is rising faster than that of natural gas fueled vehicles. The cost of the development work on 2007 diesel particulate filters and 2010 DEF systems has widened the gap between natural gas fueled and diesel fueled vehicles. Natural gas fueled vehicles, with exceptions, have remained with the simple 3-way catalyst for exhaust after treatment. There are a number of factors that, in combination, will help reduce the differential between natural gas and diesel fueled vehicles.

There will be greater competition among truck OEMs for natural gas fueled truck market customers. Natural gas fueled trucks will not just be for a very specialized market desiring cleaner air. With more customers entering the market, some of them being large customers with purchasing clout, OEMs can no longer demand high price premiums. If there is a pre-buy to beat 2014 emission and fuel economy requirements for diesels, natural gas customers in 2014 will be in demand, putting pressure on OEM pricing.

Natural gas fuel tank prices will decrease. The law of supply and demand will prevail. Natural gas fuel tanks are not some exotic component. Their construction is relative simple. Off shore manufacturers will come into the U.S. market as they try to expand what they are doing in their traditional markets. As volumes increase, OEMs will have the opportunity install fuel tanks in-house to reduce costs.

Look for advances in natural gas engine technology. One area of concentration may be direct injection of natural gas into the combustion chamber while still using a spark ignition system. There is much to be learned from gasoline engine technology where fuel is now directly injected into the combustion chamber rather than mixed in the intake manifold with carbureted systems or more modern direct injection into the intake manifold.
prior to the combustion chamber. Engine suppliers as well as OEMs have always been under pressure to improve fuel economy. The new 2014 legislation on fuel economy adds pressure. What is learned about diesel engines, such as reducing parasitic losses, in the engine can be readily adapted to natural gas engines. With greater volume of natural gas engine production, there will be additional research monies to accelerate technological research.

As in the past, customers will evaluate new technology but there must be a payback. In the case of natural gas fueled commercial vehicles, the payback looks more and more promising, prompting more and more natural gas fueled vehicle sales. In a competitive market, OEMs will identify and capitalize on ways to remove costs. At the same time, customers will look for ways to reconfigure the rest of the vehicle in a continuous process to reduce costs.

Do not look for a quick change in the current psi limit for CNG fuel tanks. Today, CNG tanks have a nominal 3,600 psi limit. When refueling, the tank is pressurized to 3,600 psi with natural gas. To get the tank full, tank filling pressures may be in the neighborhood of 4,000 psi. Now, what if the tank manufacturer could introduce technology that could double what the tank could hold to 7,200 psi? If they could, one could double the supply of fuel on board with CNG tanks with no increase in size of the tank(s). The catch is that the tank fueling structures are all based upon 3,600 psi tanks. If you had new higher capacity tanks, fuel suppliers would have to redesign their stations to fuel to the higher capacity. This would be no small investment on their part. Fuel suppliers see their role as increasing the number of fueling stations and not reconfiguring at great expense all the stations they have built already. On the other hand, on board LNG tanks can be built to the configuration(s) that the customer demands since they are not a high pressure vessel, but rather a highly insulated one.

As natural gas engine suppliers have announced future new higher engine displacement offerings with correspondingly higher horsepower and torque ratings, they were quick to note that the engines could be mated with mechanical transmissions. This is good news for anyone considering natural gas fueled vehicles for regional trucking. Limiting new engine designs to require automatic transmissions would be only a sales negative as most regional trucks are manual transmissions. Most fleet operators believe that using automatic transmissions in regional trucking is a luxury they can’t afford when the driver uses the top two gears in the transmission most of the time. So, the good news is that manual transmissions will be approved for use behind the new higher displacement natural gas fueled engines.

In summary, the gap between a natural gas fueled commercial vehicle and a similar diesel powered one will narrow. That is, the gap between the two will narrow as the economies of scale come into play in favor of natural gas fueled vehicles. Inflation will always come into play in the capital markets, but we can expect the current premium price differential for a natural gas fueled vehicle to erode in the future.
TOTAL OPERATIONAL COSTS

The acquisition costs (capital costs) for the vehicle itself have been reviewed. There are two more capital costs to consider when one contemplates natural gas fueled vehicles: Fueling stations and changes to the maintenance shop facility.

With natural gas fueling stations, there are several options. When one has a relatively small number of natural gas fueled vehicles, a nearby commercial natural gas fueling station may be a viable option. As the natural gas fleet grows, one may consider a natural gas fueling station on the property. Whether slow fill, fast fill or anything in between, there are several alternatives.

One alternative is to purchase the whole fueling station, operate and maintain the equipment, and, then, capitalize on the cost savings. Unfortunately, the cost savings come with a large capital outlay for the fueling station. There are alternatives. A natural gas fleet user could have a fuel supply company make the capital investment and, then, sell fuel on a per gallon price with a guarantee of so many gallons per month, per quarter, per year or whatever arrangement works for both parties. With this arrangement, the natural gas fueling equipment is provided along with 24 hour service support for the station’s operation. The user pays a higher price per gallon for the gas on a contract basis but did not have the capital cost of the station. Of course, there are many variations. Own the station and contract for service. Lease the station and provide for your own service. Own the station and sell natural gas to the public or other commercial vehicle operators to offset the cost of the fueling station. The point is that as with any capital good, there are costs involved and there are many ways to finance the operation. Discussions with a natural gas fuel supplier will provide all the options.

Maintenance facilities for natural gas fueled vehicles must pass local codes for safety, generally NFPA 30A. This usually means making changes/improvements to the existing facility to accommodate natural gas fueled vehicles. What the codes are designed to prevent is the possible explosion that may occur if natural gas were to escape from vehicle tanks and enter the maintenance facility and come into contact with an ignition source. If natural gas escapes, you don’t want it getting into overhead furnaces with open flames such as found in the burner, nor do you want it to be ignited by a light bulb that breaks and generates a spark.

The expense for maintenance shop conversion to code will vary. It all depends on the existing facility, what changes are required by code, and the size of the natural gas fueled vehicle maintenance facility to be built or converted. Basically, you are making sure that there is no open flame or potential for open flame and installing a detection system that will automatically open shop doors and ventilate the area if natural gas is detected.

Diesel engines are not without their own unique requirements for the maintenance facility, particularly with the changes to meet 2007 and 2010 emission requirements. How and where do you store the DEF, which is basically ammonia? How and where do you operate a vehicle that is regenerating the particulate filter?

Just operating a maintenance facility brings its own set of rules, regulations and codes. Using natural gas as a fuel merely means adapting the facility to a new set of requirements with the associated costs. The costs for making a change should be factored into the overall operational costs and decision to use natural gas.

For some natural gas fueled commercial vehicle operators, the OEM dealership will be the maintenance facility. OEM dealerships will have to make the required maintenance facility changes or see the business move to the competition. Until the commercial vehicle user’s natural gas fueled fleet size reaches some number of vehicles, it just may be the lowest total cost to rely on the dealer’s facilities.

Just because the OEM offers natural gas vehicles doesn’t mean dealers are prepared to maintain the products. Natural gas engine suppliers have had their distributors prepared for a number of years. OEM dealer support is critical for new users and partner capabilities should be reviewed.

The changes for OEM dealerships are not limited to natural gas fueled vehicles. What changes are required for hybrid vehicles with large batteries? How do you build a code approved battery charging station? As with any business, changes in technology drive changes in businesses and their respective capital costs.
When commercial vehicle operators contemplate a change to natural gas fueled vehicles, a primary concern is how to get the maintenance facility ready for vehicle maintenance, troubleshooting, and repair. The transition can be relatively easy. Natural gas engine suppliers have training courses available on the fine points of natural gas fueled engines but most of the knowledge is already in-house. A laptop computer with the appropriate software (just as with a diesel engine) is used to troubleshoot fault codes and diagnostic approaches. One doesn’t need to learn new skills, but rather expand upon the ones used with diesels. Remember, a natural gas fueled engine is approximately 80% diesel. No need to learn new skills to change a water pump, troubleshoot low boost pressure due to a small leak in an air-to-air intercooler, change an air compressor that won’t pump properly or fix an oil pan gasket leak. What will be different are the ignition system, the heart of a spark ignited natural gas engine, and the natural gas fuel system. The ignition system technology is borrowed from the technology used on today’s passenger cars and is not something entirely new to a trained technician who may already be working on gasoline powered vehicles.

Rather than fuel injectors as with diesel engines, spark ignited natural gas engines use spark plugs to ignite the mixture of natural gas and air in the combustion chamber. Natural gas fueled engines need spark plug changes at prescribed intervals. The spark plugs used are not inexpensive. They are not the same as used on passenger cars. As the volume of natural gas fueled engines increases, the cost for plugs will decrease. Spark plug life and maintenance is critical. If the engine spark plugs begin to miss, corrective action should be taken to prevent excess unburned fuel from entering the three way catalyst as the unburned fuel can damage the catalyst.

Complete periodic maintenance of a natural gas fueled engine is very similar to that of a diesel: oil and filters get changed, coolant gets treated and changed at prescribed intervals, and valve clearances get checked and reestablished to specification at prescribed intervals. When contemplating using natural gas fueled engines, it would be a good idea to compare the prescribed maintenance intervals and requirements with that of a diesel engine. What is eliminated is the need to maintain the DEF system and plan on particulate filter cleaning from time to time on most spark ignited natural gas engines. HPDI systems are unique and may require particulate filter cleaning.

A significant number of natural gas engines use a different specification lubricating oil. Ash is an additive used in diesel engines along with a package of other additives. In a natural gas engine, you do not want the ash being deposited on spark plugs, or on intake or exhaust valves. There should not be a wide variance in the price of lubricating oil used in diesels versus that used in natural gas engines. What is important is that the maintenance facility understands the difference and uses the proper specification oil in the proper engine.

One of the first things a maintenance facility just starting with natural gas will find is that when changing engine oil at the prescribed interval, it appears to be extremely clean when compared with diesel oil at the same mileage of change. With less carbon in the fuel, there is less contamination of the lubrication oil and, thus, the oil being drained from a natural gas fueled engine can look extremely clean. Even though it appears extremely clean, the additive package of the oil is exhausted and needs to be changed. Contemplate extending oil change intervals on a natural gas engine with caution and only with the help of oil and engine experts.

With a natural gas fueled engine, the efficiency of the engine is not as good as that of a diesel and, thus, the fuel economy in terms of mpg will be less, but how much less depends. A natural gas fuel engine is not as efficient as a diesel for several reasons:

- A natural gas engine (other than HPDI) has a throttle plate in the intake system while a diesel does not. The throttle is an obstruction to good air flow. For that reason, the natural gas engine is least efficient at partial throttle openings or when idling.

- A diesel engine operates at a higher compression ratio, usually in the neighborhood of 16:1 whereas a spark ignited natural gas engine operates in the neighborhood of 12:1. Generally, the higher the compression ratio, the greater the power output of the engine. When you get above the 12:1 ratio with natural gas, you can get into issues of detonation which can destroy engines in short order.
HPDI designs work around some of these limitations but present their own unique set of limitations. Remember, the design of an internal combustion engine, whether it is diesel or natural gas fueled, is the science of compromise.

So, if we are going to contemplate using natural gas engines, we need to be prepared to accept lower overall fuel economy, but that lower fuel economy is offset by the lower cost of the fuel. If the numbers calculate correctly, our operational cost will be lower, and using natural gas fueled engines will be an operational cost savings.

As we think about a comparison, a new term is emerging into our vocabulary: TFC (Total Fuel Consumed). The reason for this is that the higher diesel fuel economy is offset by the cost of the DEF, the time spent with the diesel fueled vehicle stationary with the engine running to regenerate the particulate filter, and the expense of professional cleaning of the particulate filter. All these costs must be factored into the mpg calculations. It does no good to compare only the direct outlay for fuel and not take into consideration the DEF costs and filter cleaning costs or you will arrive at invalid comparison.

To calculate if operational costs could be lower using natural gas fueled engines, you will need to work with your own assumptions. You will need to calculate TFC and not just natural gas versus diesel fuel costs. Your methodology may follow as below using your own assumptions.

**Diesel Fueled**
- Line haul usage
- 100,000 miles per year
- Overall, 6 mpg on diesel fuel
- Diesel fuel at $4.00 per gallon
- 2% usage of DEF in relation to diesel fuel consumed.
- DEF @ $2.00 per gallon
- One professional cleaning of the diesel particulate filter (Cost estimate does not include cost to remove or reinstall filter.)

**Natural Gas Fueled**
- Comparative efficiency at 90%, 85% and 80%
- 100,000 miles per year.
- DGE (diesel gallon equivalent) purchased.

### Annual Fuel Cost Comparisons

<table>
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<tr>
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<th>Diesel Fuel</th>
<th>Natural Gas @ 90% Efficiency</th>
<th>Natural Gas @ 85% Efficiency</th>
<th>Natural Gas @ 80% Efficiency</th>
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<tr>
<td>MPG</td>
<td>6.0</td>
<td>5.4</td>
<td>5.1</td>
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<tr>
<td>Gallons of fuel required for 100,000 miles</td>
<td>16,667</td>
<td>18,519</td>
<td>19,608</td>
<td>20,833</td>
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<tr>
<td>Cost of fuel at $4.00 per gallon</td>
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<td>--</td>
</tr>
<tr>
<td>Cost of natural gas fuel at $2.50 per gallon DGE</td>
<td>$46,298</td>
<td>$49,020</td>
<td>$52,083</td>
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<tr>
<td>DEF consumption in gallons</td>
<td>333.34</td>
<td>Not Required</td>
<td>Not Required</td>
<td>Not Required</td>
</tr>
<tr>
<td>DEF cost at $2.00 per gallon</td>
<td>$666.68</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Diesel particulate filter cleaning</td>
<td>$275.00</td>
<td>Not Required</td>
<td>Not Required</td>
<td>Not Required</td>
</tr>
<tr>
<td>Total fuel cost</td>
<td>$67,610</td>
<td>$46,298</td>
<td>$49,020</td>
<td>$52,083</td>
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<tr>
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<td>$92,950</td>
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Some observations can be made from the above assumptions and calculations. Although natural gas fueled engines might not be as efficient as diesel, the lower cost of fuel has a dramatic impact on total fuel costs. Multiple natural gas fueled truck purchases often offset capital required to upgrade a maintenance facility to natural gas code in just one year. The higher cost of the natural gas fueled vehicle and any fueling station must be factored in as well.

It should be clear why those fleets, such as refuse, which do not accumulate high mileages but which have high hours of operation and consume large amounts of fuel due to their duty cycles benefit from the cost savings differential between diesel fuel and natural gas.

The actual difference in operational efficiency between the two different fueled engines is subject to many variables. In line haul, you can get the engine in a top gear cruise condition and this minimizes the efficiency differential. In addition, with natural gas fueled engines coming available next year aimed at the line haul markets, with the overall competitive engineering focus on fuel economy, and the 2014 truck fuel economy standards, it is a realistic assumption that overall efficiency of the natural gas engine will improve compared to diesel.

What we can't know yet is the reduction both natural gas and diesel fueled engines will take on fuel economy, if any, as the new GHG (Green House Gas) emission laws take effect in 2014. Only time will tell. However, anything done to improve fuel economy reduces the GHG emissions. Perhaps the new regulations will bring an improvement in fuel economy.

When looking at the dollar savings available in using natural gas fueled engines for line haul, one has to ask where else one can find the overall ongoing cost reductions a fleet needs to remain competitive in the market place. The low hanging fruit in fuel cost reductions, such as the following, should have been picked already:

- Driver road speed control
- Reduced engine idle time
- Controls to keep the vehicle in the fuel efficient top gear
- Overall tractor/trailer aerodynamics
- Driver training

Where else can you find the significant operational cost reductions available with natural gas fueled engines? If the competition can get anywhere near the fuel cost savings outlined with the given assumptions, you know what they can do with their rates. Fleets looking at natural gas fueled engines in their fleets have the potential to take more profits directly to the bottom line, cut freight rates and gain more freight, cutting overhead cost per mile, or some combination. There is much potential to make a change in the industry.
ENVIRONMENTAL CONSIDERATIONS

Everyone wants clean air until it is time to pay the bill for costs associated with it. For example:

- Do fleets purchase trucks that have the lowest emissions or do they buy what legally meets the current emission certification level?
- Do fleets purchase trucks whose engines do not meet the current emission specification but are legal for sale due to emission credits or other reasons?
- Do fleets pre-buy to avoid meeting more restrictive emission standards?

Fleets buy commercial vehicles on the basis of perceived value. Can they make money with the capital assets (trucks) in their operations where the freight rates are, to a large degree, set by shippers? If the asset is legal for sale, it will be considered.

Early adopters of natural gas fueled trucks generally purchased vehicles on the basis of cleaner air. Grant requests to get funds to offset the higher cost of the natural gas fueled vehicles generally mentioned the amount of particulate reductions possible to clean the air. The differences were significant. Before we got to the 2010 emission standards, the differences between natural gas fueled engines and diesels were significant. Although the emission specifications were written in grams per brake horsepower per hour, the differences were measured in tons of particulates and nitrogen oxides over the expected life of the engines. Back then, there was a price differential in the cost of the fuels but nothing like it is today. Today, the emission differences are still significant, but their overall magnitude is substantially reduced. While the order of magnitude in the emission characteristics narrowed, the price differential between the two fuels widened.

For 2014, the emphasis will be reducing GHG (Green House Gases). The jury is still out on what will happen to engine performance, maintenance costs, expected engine life, etc. The fact remains, however, that we have started down the road to reducing GHG. When emission laws were first passed to begin in 1970 to reduce particulates and NOx, the first steps appeared to be relatively easy to meet. Few envisioned how drastic the changes would be by 2010. Can we expect the same march on GHG? Where might we be in 40 years? Which engine, natural gas fueled or diesel fueled, will find the new requirements easier to meet? We don’t have clear answers yet.

What has evolved is that fuel economy is not the prime determinant of which type of fuel for an engine is best because there is no longer just one prime determinant. Instead, we have several prime determinants:

- overall fuel economy
- long term fuel availability
- fuel cost
- emission characteristics
- engine reliability and durability
- national and world politics
- national security, and
- a host of others.

In trying to find the best overall solution, natural gas fueled engines have tremendous potential to have a major impact in all the areas of concern.

In the commercial vehicle market, lowest total cost and a competitive advantage are keys to long term profitability and survival itself. Commercial vehicle users will look to natural gas fueled vehicles, not because they have been cleaner on emissions and still are, but because of the potential for real operating cost reductions.

Previously it was mentioned that LNG fuel tanks can vent natural gas to the atmosphere. This should not be an environmental concern. No operator of an LNG fueled natural gas powered truck wants to pay for LNG fuel and, then, see it wasted or lost because it is vented to the atmosphere. LNG fuel tank venting is a safety device built into the fuel supply system just in case there is excess pressure. An LNG filled tank on a truck moving down the road or even stopped at a stop light will not be venting methane to the atmosphere. The natural gas engine will be using the natural gas to produce power. Only if the LNG fueled vehicle is sitting in extreme heat for a long period of time without the fuel tank(s) supplying fuel to the engine might the tank(s) vent a small amount of natural gas if the pressure inside the LNG tank reaches a certain point.

Another name for natural gas is methane. If one were to read a Wikipedia definition of natural gas or methane, one would learn that methane is a
greenhouse gas if it is released into the atmosphere but methane (again, natural gas) is burned in a natural gas engine to produce power. The product of burning the natural gas is power (the rotation of the crankshaft), heat to the cooling system and exhaust gas that only has trace amounts of methane. Natural gas engine developers as well as enacted legislation aims at reducing any amount of methane out the exhaust of a natural gas fueled engine. Minimizing any methane coming out the exhaust maximizes the fuel economy of the engine while at the same time maximizing the power output.

LNG fuel tank venting is a very minimal source of a greenhouse gas. A much larger source is what is given off at refuse sites, marsh and swamp gas as well as flatulence from dairy cows.
OPERATIONAL REALITIES

We are all creatures of habit. Change comes slowly because we fear the unknown. The use of natural gas fueled vehicles represents change. Unless they were early adopters for emission reduction reasons, new purchasers are being asked to take a leap of faith. Commercial vehicle operators can drive a natural gas powered truck, particularly the coming 12, 13, and 15 liter versions, and determine if it meets performance and duty cycle expectations.

In years past, the terms “cruise power” and “reserve power” were strategies in spec’ing diesel powered line haul trucks. Trucks were spec’d with enough power so that they could cruise the interstate at 65 mph and stay with the flow of traffic. The truck was run in the top gear (could be overdrive) and the engine operating in the “sweet spot,” the engine rpm where engine fuel economy was optimized. The “sweet spot” was a relatively narrow band of rpm where the engine produced the power required for cruise performance but burned the least amount of fuel. The reserve power part came in when the vehicle needed to climb a grade, pass a slower moving vehicle, ease into traffic from the expressway on-ramp, or other situations where a little extra power was needed.

The downside to this approach was that some drivers would cruise in a lower gear (higher engine rpm) because they liked the more responsive feel of the truck or the driver used the extra power to drive at a higher road speed. Engine design engineers soon found ways to program the electronic controls to prevent drivers from doing this, such as road speed control and gear down protection.

Natural gas engines used today (not those coming next year and excluding higher horsepower HPDI engines of 450+ horsepower) were adequate/marginal in horsepower and torque. That is, they got the job done but had little if any reserve power. They worked in refuse trucks and bus applications where sometimes traffic congestion controlled how fast a vehicle could go or how fast it might accelerate. They really weren’t aimed at the line haul market.

On paper, the horsepower and torque characteristics of a natural gas engine would not have been one’s first choice for line haul. The trade off for the refuse truck driver was that he or she operated a quieter engine with cleaner emissions but just adequate performance.

Diesel powered line haul fleets were making performance choices of their own when it came to spec’ing trucks. As the price of fuel kept escalating, companies needed some cost relief. Fleets did so by cutting back on the amount of reserve power they purchased in new trucks. Smaller displacement diesel engines were ordered with lower horsepower and torque ratings. Rear axle ratios were changed to favor fuel economy over performance while still trying to protect overall vehicle start-ability and grade-ability. Lower overall road speeds were electronically programmed into the electronic controls. All this was done in an effort to gain fuel economy while still retaining drivers to drive the trucks. With driver turnover rates as high as 100%+ in some fleets, how can one spec for better fuel economy and not performance? If you were a truck driver and did not have to pay for the truck or the fuel burned, which truck would you want to drive --- one that has performance or fuel economy? For fleet managers, there were some tough decisions. How do you spec for fuel economy and still retain drivers?

With the announcement by natural gas engine manufacturers that they would be delivering engines next year (2013) with horsepower and torque characteristics equaling existing diesels, fleets could now spec natural gas powered trucks for line haul operation and feel comfortable that drivers would accept them. Performance with natural gas engines for line haul would not be an issue. Today, some applications of natural gas powered trucks may be marginal when compared with diesels. Tomorrow, the new natural gas engines with increased performance will change that perception. The natural gas engines will deliver the same performance, with less noise, with reduced exhaust in a package that promises lower cost per mile.

What commercial vehicle operators can’t do is insure that the planned increase in the number and positioning of natural gas fueling stations will really materialize. Similarly, commercial vehicle operators have no way of knowing if there really are proven reserves of natural gas to provide a 100 year supply.
What if the experts are wrong and the current fuel price differential is an aberration and not a long-term trend? What if commercial vehicle operators begin a movement to natural gas fueled vehicles as the new engines become available and the above fears are realized? Will they own some very expensive equipment with little or no residual value?

These are tough questions indeed. But what if all or a portion of new advantages of natural gas fueled commercial vehicles are true? What then?

If a commercial fueling station is reasonably close, commercial vehicle operators can purchase a small quantity of natural gas fueled vehicles to test the claimed advantages. The new test sample(s) of natural gas fueled vehicles can be maintained by the dealer who has code-compliant maintenance facilities or, when appropriate, vehicle maintenance can be performed outside. The big unknown is the proximity of the fueling station.

With OEM information, industry forums, industry associations and the usual industry contacts, operators will discover if the claimed natural gas fueled cost advantages are real. Similarly, any transition hiccups to natural gas will come to light. The problem for everyone is that if the operational cost savings are real and there is an order of magnitude on the fuel cost savings, then there could be pressure on rates. In a very competitive industry, standing pat is not an option.

If one or more commercial vehicle operators have good initial success, other operators will be forced to follow. What happens then? Consider the following:

- **Higher capital costs for new equipment:** The cost differentials between natural gas and diesel are expected to decrease, but initially the equipment will cost more. The future cost of fuel to operate the vehicle becomes a greater concern over the life of the vehicle than the initial capital costs for the vehicle.
- **Investment in the maintenance facility:** Just finished building a new maintenance shop without considering the use of natural gas? Tough break. Thinking of building a new facility in the next year or two? Great timing on your part as you can incorporate code requirements in the beginning.
- **Positioning of fueling stations:** If there is a commercial operation close, then you are in luck. If not, you are looking at a major investment, but there are options to finance a new station. The greater your investment, the lower the cost of the natural gas fuel. The more you rely on others to supply the capital, the higher your costs for fuel. Do I use LNG or CNG? Industry practice will dictate what you do. The decision will come down to how much fuel you want to carry on the vehicle, how often you want to buy fuel on the road, and where you can buy fuel on the road.

The transitioning to proper maintenance on the natural gas fueled vehicles will be the easy part. It will be no different than when you learned how to operate and maintain diesel particulate filters and DEF systems. Your technicians already understand fault codes, laptop assisted trouble shooting, and coil-on-plug ignition systems. Training is available, but technicians already have years of experience working on 80% of the engine that is the same as a diesel.

What about fueling times for CNG or LNG fueled vehicles other than planned slow fill systems where vehicles are parked and out of service? With normal refueling of a natural gas fueled vehicle, how long does it take? Is the time the same as for refueling a diesel? The answer is, it depends.

The fill rate for diesel fuel tanks is somewhat standardized. The flow is a constant amount. Electric fuel pumps provide diesel from (generally) underground fuel storage tanks through a metering system into the diesel fuel tank.

The process for fueling an LNG system is similar. Since it is a cryogenic fuel, protective gloves are worn along with a protective face shield. Tank filling time is about the same as for a diesel. With a CNG fuel supply system, it could take longer. How much volume and how much pressure is in the CNG supply tank? If the filling station has a large natural gas compressor and lots of storage volume, the CNG tanks can be filled in short order. However, when the temperature of the compressed fuel is high, it is hard to get a complete fill of the tanks. If the fueling supply for a CNG system has a smaller compressor and limited compressed natural gas storage supply, then it will take longer to fuel the vehicle. The short answer, then, is CNG tank filling time is a function of the CNG fueling...
station capacity. At best, it might take a few more minutes than a diesel fueling station to fill CNG fuel tanks.

The greater question is really what happens when a truck (diesel or natural gas) refuels. It is never a NASCAR type fueling stop. Is a pump available or are you next (or second or third) in line. Is the fueling stop also a rest break for the driver? Will he or she want to stretch his or her legs, use the restroom, get some refreshments, get on the Internet, have a meal, do a walk around safely check, tilt the hood and do a fluids check, check the DEF supply and perhaps add fluid, or the multitude of things that get done at a refueling stop? It may take a few minutes more to fill a CNG tank, but the increased time is not a show stopper. So the question of which one can you fuel faster can become a moot point.

In summary, the availability of appropriate natural gas fueling stations and the availability of the new higher horsepower natural gas fueled engines will dictate how fast the transition occurs. The observed real economics of fuel cost per mile using natural gas will greatly influence the momentum behind the transition. Everything appears primed for an orderly transition.
POLITICAL REALITIES

In the past, there have been financial incentives to utilize natural gas as a transportation fuel. Federal government support that ended in 2010 included:

- a combined 80% tax credit to cover the premium price for a natural gas powered vehicle over a similar diesel powered vehicle up to a maximum of $32,000 differential, and
- a 50 cents a DGE fuel cost rebate.

In addition, there could have been local and state incentives to utilize natural gas fuel for commercial vehicles. Given the limitations of natural gas fueled commercial vehicles, early adopters who were willing to utilize natural gas fueled vehicles got both clean air and a net discount on the purchase of vehicles. OEMs got a premium for the vehicle, early adopters got a bargain, and the taxpayers paid the difference. Today and tomorrow, the reasons to adopt natural gas fueled commercial vehicles are more economic than political in the way of incentives.

According to a Canadian study (“Natural Gas Use in the Canadian Transportation Sector,” prepared by the Natural Gas Use in Transportation Roundtable, December 2010), the number of natural gas powered vehicles in the United States stood at 105,000 in 2000. By 2004, it had climbed to 121,249 vehicles when the number of total units began to decline. About mid-decade, a number of OEMs stopped producing natural gas fueled vehicles. By 2009, there were 110,000 natural gas fueled vehicles with 1,300 fueling stations supporting these vehicles. In fact, the supply of natural gas reserves was thought to be declining. By 2010, the outlook changed from that of rapidly declining production to rapidly growing production due to frac’ing.

Frac’ing, or more correctly fracturing, is a process developed to capture natural gas from shale rock formations. In the United States, the process has been enormously successful. Basically, horizontal wells are driven from one platform and then slickwater (fresh water with friction reducing chemicals added) is mixed with sand and pumped...
into the shale rock at high pressure. The fluid under pressure shatters the shale into pieces to allow the gas to be collected. The sand keeps the fractures open so that the gas continues to flow. The frac’ing process, as opposed to conventional vertical drilling into suspected natural gas pockets, has helped produce a glut of natural gas that has driven the price of natural gas below $2.00 DGE.

To get an idea of how dramatic is the change in natural gas production, look at the increase in gas production in Pennsylvania as an example, shown in the graph below. Natural gas is here in the United States and it is abundant.

Despite the gains, the frac’ing process is not without its critics. Some would say that frac’ing:

- releases harmful chemicals into the ground water,
- can cause earthquakes, and
- releases harmful chemicals into the atmosphere.

The problem is we can’t easily confirm these criticisms without additional study. What if the above criticisms are true? On the other hand, additional study might show that what is now being done to retrieve coal and oil causes the very problems that we blame on natural gas extraction.

Your answer to the above concerns may depend upon the state in which you live, how you earn you income, and/or alternatives that you propose. The overall problem for everyone is that the United States has an enormous appetite for energy. Americans want to do the right thing but at the same time, don’t want any of freedoms to use the energy as they see fit curtailed. This is where politics will continue to enter into the picture.

Think about how much oil is imported into the United States each day. The U.S. is the top world importer of oil. Politically, Americans pay a price for being the world’s top importer. As China increases its demand for oil, what will happen to the world price of oil?
In the last few years, frac’ing has helped increase the known reserves of natural gas exponentially. Consider the graphic below.

As we think about alternatives to this new abundance of natural gas which has been found in the United States, we need to think about the energy we are currently using. How much of the energy we consume as diesel fuel comes from the Middle East? How stable are the governments in the countries with proven oil reserves? Are they really our future partners?

Obviously, the above questions are tough ones with no simple answers. They have been asked repeatedly. Politicians have assured Americans that they have attempted to get definitive answers over the years and have invested much time and effort. In the meantime, Americans fuel their cars and commercial vehicles as if the supply of energy will exist without any interruption.

With an abundant supply of natural gas, the U.S. could quickly become a net exporter to the world. Worldwide commodity pricing would apply. This raises the question of what would happen to the price of natural gas, more specifically, the DGE price, if the U.S. became an exporter of natural gas energy?

Economists have predicted that there would not be a major price increase in a DGE of natural gas if alternative uses of the natural gas supply were implemented. If the projections are believed, it would take wide latitude in changes of natural gas usage before there would be a negative impact on the pricing of a DGE of natural gas. Asserting that natural gas prices will skyrocket to or past the current price of a gallon of diesel fuel if the number of natural gas fueled commercial vehicles dramatically increases and they consume large quantities of fuel can’t be justified. There is an abundance of natural gas in the United States and...and new drilling techniques have increased estimated U.S. natural gas reserves by 50%.

- Shale gas drilling methods have expanded U.S. reserves 50% (from 1,700 to 2,600 trillion cubic feet.)
- 2,600 trillion cubic feet can supply U.S. domestic needs for > 100 years.
it can be used for fueling natural gas powered commercial vehicles without adversely impacting the current advantageous per gallon pricing structure of natural gas versus diesel.

The more the natural gas fueling infrastructure develops in the United States, the less dependent its citizens become on the world supply of energy.

Will new government programs to promote natural gas usage be implemented? Will state and local governments follow with incentive packages? In the past, cleaner air was the rallying point for the various incentive programs. Today, the emission differentials between natural gas and diesel are much smaller, but what has changed is the economics. Today, natural gas is the much less expensive fuel. Should government money be spent to promote natural gas because it is cheaper? Should incentive money be spent to promote natural gas for energy independence?

ACT can’t answer these questions. Regardless of political thought, pure capitalism is bringing about change. OEMs, engine suppliers, and fuel suppliers are betting big dollars that the economics are primed for change to natural gas fuels. It remains to be seen what, if any, incentives to change to natural gas as a fuel for commercial vehicles will be available in the future.
LAWS OF SUPPLY AND DEMAND

Currently, natural gas engine suppliers, truck OEMs, and natural gas fueling station suppliers are each looking over their respective shoulders. Will each segment do its part? Will there be a steady increase in the number of fueling stations and natural gas fueled vehicles? Are the current projected savings in using natural gas as a fuel for commercial vehicles real and can those savings be considered into the future?

The whole industry started down this road before. Recall the comments of how the natural gas fueled vehicle market rose and then began to fall in the middle of the last decade. Prior financial incentives for early adopters tried to prime the pump for expansion, but the market didn’t climb as many had expected. So, what is different this time?

This time the laws of supply and demand clearly enter the picture. In the past, before the impact of frac’ing of shale was clearly understood, there was no change in the law of supply. To make a major splash in the economics of running a natural gas powered vehicle, a major breakthrough in the fuel economy differential between a natural gas fueled engine and a diesel fueled vehicle along the order of magnitude of the diesel engine over gas as in the 1930s would have been required. The difference today is the new abundance of natural gas and how it is priced with the supply.

We can expect the current price differential to continue. Look at the chart supplied by Clean Energy Fuels.

The chart reflects how the differential has risen between the spot, or market, price of a barrel of crude oil and a million BTUs of natural gas. The differential was in the range of 6 to 12 times but with the results of frac’ing, the differential jumped to 33.4 in January 2012. This pricing reflects the belief that the overabundance of natural gas is real. If the overabundance was not believed, you would not see this differential in pricing. There do not appear to be any show stoppers such as a major shift in the use of natural gas that would adversely impact the price of natural gas as fuel for commercial vehicles.

Will we see minor variations in natural gas pricing? Yes, as there are variations in natural gas usage that go along with the heating and cooling seasons, much like what is seen today with gasoline pricing over heavy travel holidays. Major companies are making big economic bets that the differential in pricing is real and will remain into the foreseeable future.

If the demand shifts toward natural gas fueled trucks, will there be enough engines for a rapid increase? First, there are reasonable lead times expected by customers for commercial vehicles. Those customer expectations change with market supply and demand. Truck manufacturers very carefully monitor incoming order rates with vehicle build rates to smooth the build process. Every manufacturer wants to have orders in the pipeline. Second, the transition to increased natural gas fueled trucks will be orderly. It will not be as though demand changes overnight. There will be an orderly transition. The law of supply and demand will prevail.
How fast can the natural gas engine suppliers produce the new products? As ACT has outlined, approximately 80% of a natural gas engine is the same as a diesel engine. Natural gas engines can be built on the same assembly lines as diesel engines. Some of the components are unique but there are no show stoppers. The driving force in any change for the natural gas engine suppliers will be the number of test cells that have natural gas fueling and appropriate testing equipment.

Some might suggest that a show stopper is the used truck market for natural gas powered vehicles. If there is no secondary market for trucks, then the normal supply and demand pricing model would fail. This premise would suggest that since one could not readily sell a natural gas powered commercial vehicle as a used truck, the actual price or life cycle cost for a natural gas fueled vehicle will be much higher than expected. What we are seeing, however, is a change in the market for used diesel powered equipment.

Remember how used higher mileage diesel powered tractors found their way to the ports? It was a natural progression. Now the ports don’t want the used diesel powered equipment because of the overall negative emissions impact to the area. So, where do these older diesel powered used vehicles go?

Similarly, won’t used natural gas powered vehicles be in demand in port areas as used trucks? Even as used trucks, won’t their emission characteristics be better than some of the newest diesels?

In another vein, can we continue to expect to be able to export 2007 and 2010 diesel powered vehicles with their higher cost of operation due to aftertreatment solutions? Will the world market be looking for natural gas powered used vehicles that can be used in countries that already embrace natural gas fueled vehicles? In some parts of the world, natural gas fuel standards differ from those in the U.S., but there are enough similarities that the used vehicles can operate successfully.

Similarly, natural gas engine installation in an OEM chassis is well understood. Again, 80% of the parts in the engine and its physical size are the same for the OEM. There can be minor differences for the installation compared with diesel, but there are no show stoppers. What is different for the OEMs is to have natural gas vehicle fueling on site to allow for complete vehicle testing.

If there was a change overnight from diesel to natural gas, there would be problems supplying enough fuel tanks whether they are CNG or LNG. Tanks are not a high technology item. If there is an orderly transition, we can expect an increase in the supply of both.

If the market for natural gas fueled commercial vehicles increases dramatically, there are other natural gas engine suppliers, vehicle engine assemblers, and tank manufacturers that could enter the market. Engine and truck manufacturers respond to global market opportunities.

How fast will the change to a sustained percentage increase in natural gas fuel vehicles take? ACT believes it will be an orderly transition. Consider what happened with diesels. Diesel powered trucks had humble beginning in the 1930s. By the 1980s, nearly 100% of the heavy duty line haul fleet was diesel. Medium duty trucks were to a large percentage powered with diesels. By the late 1980s the pickup truck market was offering diesel powered options. It took 50 years for the transition to be almost complete for heavy duty commercial vehicles. The change to natural gas fueled commercial vehicles will take some time, but not as long as the transition to diesel.

It wasn’t until the 1970s that the push for cleaner emissions from the diesel started. Now we have demands for cleaner air, lower prices for energy, worldwide security, and a host of other political and social issues driving the demand for natural gas fueled vehicles. All these factors will reduce the transition time.

In summary, an orderly transition to natural gas fueled commercial vehicles is expected. It will not happen overnight, but in a more orderly fashion and at a faster rate than most people contemplate. New, more market acceptable trucks with natural gas fueled engines are scheduled for release in 2013 and 2014. Fueling station expansion commitments have been announced and funded. The supply of natural gas is abundant and believed to be abundant for years to come. Everything seems to be in place to allow the laws of supply and demand to prevail without incentives.
TECHNICAL FACTORS

Some might question the wisdom of contemplating natural gas as a fuel for commercial vehicles when it is known that natural gas burning internal combustion engines are not as efficient as those fueled by diesel. Technically, the argument is true without considering the fuel cost and lower emissions, but these factors change the situation.

New advancements are on the horizon for natural gas fueled engines that will improve fuel economy, such as changes to the direct injection of natural gas into the combustion chamber. As with a gasoline engine, the temperature of combustion is reduced because the fuel cools the combustion chamber as opposed to being heated in the intake manifold when mixed with air in advance of entering the combustion chamber. The end result is reduced emissions, more power, and better fuel economy.

Advances in ignition systems, allowing consistent firing of the natural gas and air mixture in the combustion chamber are expected. With everything that is learned about combustion, whether it is for a diesel or natural gas, improvements in fuel economy will continue for both engine types. From an engineering standpoint, it is a continuous process.

Despite the fact that design engineers have been working on internal combustion engines for years, small improvements occur without an exponential increase in fuel economy. As outlined in the engine basics section, supercharging, turbocharging, and aftercooling have already been adapted. Next, we will see continuous refinements in all these areas. Ever heard of electrically boosted turbochargers to help an engine accelerate faster to reduce turbo lag? Development work continues in all areas for both natural gas and diesel because it makes competitive sense and because the laws on emissions and fuel economy dictate it.

Despite all the work that has been done with internal combustion engines over the years, we generally get only one third of the energy in any fuel as power which rotates the crankshaft, one third as heat to the radiator, and one third as heat out the exhaust. We get small improvements over time but no exponential improvements. Sometimes what you may do to improve fuel economy hurts engine emission characteristics and engineers have to find other ways to recover what they lost.

With the 2010 emission laws and the advent of DEF aftertreatment, design engineers have been able to improve combustion chamber efficiency with diesel engines knowing that they can use the DEF to meet overall emission legislation. It is a constant compromise to balance how much efficiency can be gained in the combustion chamber and how much will be offset by the need for incremental amounts of DEF.

Most fleet managers say that despite all the work to improve engine fuel economy, the driver may be good for one mile per gallon. How the driver operates the commercial vehicle dramatically impacts overall fuel economy. How fast is the vehicle being driven? How much time is spent with the engine needlessly idling? Are progressive shifting techniques being used? Is there needless downshifting when the driver should remain in top gear? All these factors as well as overall vehicle design have a tremendous impact on overall fuel economy. Fuel economy is not just a function of engine design.

As previously discussed, a natural gas fueled engine is not as efficient as a diesel engine when idling. In a diesel engine, there is no throttle plate in the air intake system. Air is constantly being pumped through the engine. The amount of diesel fuel mixed with the air determines the power of engine output. With a natural gas fueled engine, there is a throttle plate that restricts the airflow through the engine. The throttle plate limits the amount of air and fuel mixed and controls the amount of fuel-air mixture going into the combustion chamber. When the natural gas engine has some type of fuel injection either into the intake manifold or directly into the combustion chamber, the amount of air entering the combustion chamber has to be controlled or the proper fuel mixture (generally 14:1, that is 14 parts air mixed to one part of fuel) would be disturbed to the point that the engine would not operate. Controlling airflow with a throttle plate makes the engine work to overcome the throttle restriction which uses more fuel than a diesel at idle. This is not all bad as it allows a gasoline or natural gas fueled engine to use less expensive exhaust after treatment.

Since there is no excess air (oxygen) downstream of the combustion chamber in a spark ignited
engine (which uses a throttle plate), the catalyst can be used. If there is excess air as with a diesel which does not use a throttle plate, a simple three way catalyst can’t be used.

If a natural gas engine is being compared with a diesel engine in a vehicle duty cycle where there is often idling, the natural gas engine will not be as efficient. Correspondingly, when the natural gas engine is used in a vehicle duty cycle where there is little idling (such as in line haul), the fuel consumption characteristics of the two types of engines are much closer together. Ever wonder why refuse truck operators have led the change to natural gas fueled engine? Despite the theoretical differences in idle fuel characteristics, natural gas is the cheaper fuel to use since it costs so much less and the cost per mile, including all of the idle time, favors the use of natural gas.

Natural gas fuel can be utilized in two forms: CNG and LNG. Over time, natural gas engine users will decide what works best for them. Although LNG offers its own set of advantages, it does come with a higher cost. LNG is nothing more than CNG that has been cooled to minus 260 degrees F and that cooling costs money.

CNG at approximately 3,600 psi takes up 1/300 of the space it would occupy at normal atmospheric pressure. LNG takes up 1/600 of the space it would occupy at normal atmospheric pressure. Here is a quick summary of the pros and cons of each form of the same fuel, natural gas:

**CNG:**
- This is the less costly of the two forms.
- There are at least four types of tanks available at different weights and costs.
- In a slow tank fill process, such as with slow fill system, it is easiest to get a full tank of fuel because the tank(s) are able to dissipate the heat of compression of the natural gas and, thus, get a denser full fill.
- Conversely, it is harder to get a full fill with a fast fill system.
- Multiple tanks can be placed at multiple locations on the vehicle.
- Least costly tanks generally weigh the most; adding even one increases the non-payload weight to the vehicle.

**LNG:**
- Metal tanks have the greatest ability to dissipate the heat of compression when filling tanks, particularly fast fill systems.
- Lighter composite tanks don’t dissipate the heat of compression as well as heavier metal tanks.
- This type of natural gas provides for the most fuel on board in the least amount of space.
- Vehicle weight increase is minimized.
- LNG provides for the minimum amount of fill time of about 50 gallons per minute. Fill time is very similar to diesel fill times. This can be an important point when filling from commercial sites on the road as opposed to filling at a home station.
- The liquefaction process adds costs compared to CNG.
- LNG fuel tanks are really large thermos bottles (to keep the fuel cold) but they weigh much less than CNG tanks.
- An on-site LNG station costs more to build because it involves fuel cooling systems.
- LNG can be delivered in special tankers very similar to bulk diesel fuel deliveries.
- When delivered in bulk, it can be converted back to CNG but then cost of the step to make the LNG is lost in the process and the fuel costs more than simple CNG.
- LNG can be delivered to remote U.S. regions where there is no natural gas delivery system.
- Fuel can be lost to the atmosphere as the LNG fuel vents due to pressure build up in the LNG tank. This is called “weathering.” At the top of the liquid inside the tank, the natural gas is in a gaseous state. In one sense, the LNG is trying to become a gas but is being held as a liquid. The gaseous state is what the engine uses. The LNG tank is not designed to hold natural gas as a liquid and as a gas. If the LNG tank had to hold natural gas as a liquid and as a gas, the tank would be extremely heavy and the weight savings would be negated.
● If an LNG tank sits unused, it will continue to vent the natural gas over time. When it is used in normal operation, the LNG which converts to a gaseous state is used by the engine. Remember, the natural gas engine uses the fuel as a gas, not a liquid.

● The vehicle is plumbed with a natural gas vent tube (to vent excess pressure) to the highest point of the vehicle. If the LNG tanks vents, it vents harmlessly to the atmosphere.

● LNG is a cryogenic fuel and, thus, precautions (face shield and insulated gloves) must be taken when refueling.

There is a third form of natural gas and it is referred to as RNG, renewable natural gas. It comes from the natural gas that is collected at refuse sites, dairy cattle sites and other sites where methane gas is naturally produced.

Most modern natural gas fueled engines are designed to use either CNG or LNG fueling systems. The engine doesn't care as it will be using the fuel as a gas, not as a liquid. In a CNG system, a pressure regulator reduces the gas from a maximum 3,600 psi pressure to the approximately 75 – 150 psi where the engine fuel control system determines how much fuel is flowing to the engine in relation to the driver's demands as the foot throttle is actuated. In the case of an LNG tank, the pressure in the tank may be allowed to rise before it vents but not exceeding the design limitations of the tank. When the natural gas engine is running and in normal service, it is taking fuel from the LNG tank at a rate where excess pressures are prevented and venting doesn’t occur.

Technology improvements will continue to be made in both diesel and natural gas fueled engines. One can have theoretical discussions on which engine is more efficient and will be more efficient in the future. However, for commercial vehicle operations, the practical question is which fuel provides the lowest TFC per mile. With cost as the overriding determinant, commercial vehicle operators will decide which fuel form, CNG or LNG, provides the lowest total cost. Fortunately, there are two forms of natural gas that assist customers, depending on whether they gross-out or cube-out their payload first.
COMPETITION FOR TRUCKS

Does any potential switch to natural gas fuel for commercial vehicles change the competition between railroads, intermodal, air or barge traffic? Obviously, it will not have an impact on air. Aircraft designers are not about to experiment with natural gas tanks for aircraft where weight reduction is high on the list of priorities. With the three remaining, there is potential.

Consider for a moment some incremental change that happens at U.S. ports of entry for ships. Changing older model diesel powered trucks for new ones powered by cleaner natural gas reduced overall pollution. Ships docking at the ports were also contributors to overall pollution burning bunker fuel in the ship’s propulsion and generating systems. To reduce overall air pollution, natural gas powered electrical generators on mobile platforms were moved dockside and cleaner natural gas provided the electrical power for the docked ships. This allowed ship operators to shut down the more polluting electrical power generation.

Will we see a shift in freight moving from trucks to rail, to intermodal or barge traffic? ACT would not expect a change. The factors within the economic model of moving raw materials, in process material, and finished goods will have to change before we will see a shift. As freight haulers adopt natural gas fueled trucks, their individual cost structure will change allowing them to gain a freight movement cost advantage naturally from those who do not adopt natural gas fueled engines.

Can railroads adopt natural gas fueled engines for the locomotives? Yes. Many of the industrial engines that power diesel locomotives have natural gas fueled models that could be adapted to drive electrical generators that power the wheels in locomotives. Rather than large diesel fuel tanks on board the locomotive, an LNG tender could accompany the locomotive. Does it require a change in traditional operations, space for locomotives with tender, LNG fueling points and a host of other changes? Yes, but what if the impact dramatically changes the cost structure? The changes could be adopted.

Similarly for barge operators, they could change from marine diesel power to boats with engines fueled by natural gas. Would it require change? Yes, just as in the railroad change scenario outlined above. Intermodal would be no different. It would require changes in each of the elements.
INDUSTRY ALTERNATIVES

Many alternatives to natural gas or diesel to power commercial vehicles exist, ranging from burning wood or coal to make steam to nuclear reactors providing power. Each alternative has dollar cost implications as well as social cost implications. Capitalism and the law of supply and demand help find the best alternatives.

Options are being tried. U.S. businesses have experimented with ethanol, solar, and wind power to generate electricity, converting French fry cooking oil to diesel fuel, etc, but the conversation comes back to reality when factors of viability, profit, and social expense are discussed. Are we going to import the energy with the political and economic ramifications or will we find it in the United States?

To be considered long term, the energy needs to be a lower cost alternative without taxpayer subsidies. It must be sustainable without negatively impacting something else such as food production. If the energy form was renewable in the long term, it would be a definite plus. If it solves other problems, such as methane escaping into the atmosphere, it would also be a plus.

The fact remains that no matter what energy source we use for commercial vehicles, some group(s) may object with legitimate concerns. Action(s) will be taken to raise roadblocks to change or to restrict the movement of capital. All too often, we will hear the cry of “Not in my back yard!”

There never will be a perfect answer. Each alternative poses its own advantages, risks, and consequences. Besides the pure economic decision, politics will get involved. Change is always difficult. Cries of “Let’s wait and study it some more,” “Tax it to death,” “OK, but don’t start with me,” come to mind.

Using natural gas as a transportation fuel in internal combustion engines used in commercial vehicles as an alternative to diesel provides the United States:

- A lower cost alternative to diesel fuel
- Less environmental pollution than diesel
- Renewable energy from refuse sites
- Less costly engine aftertreatment systems
- A local source for fuel in the United States which has enormous favorable political and economic aspects
- An easy transition to an alternative fuel:
  - Large carryover of technology in the internal combustion engine
  - Uses technology understood by technicians with any experience with gaseous fueling systems and coil over plug ignitions systems found in modern day gasoline powered passenger cars and trucks
- Less noise pollution than from diesels

On the negative side, how much do we really know about the long term impact of frac’ing? What will we ultimately know about groundwater contamination, if any, and the impact, if any, on the occurrence of earthquakes? By the same token, what do we know about vertical drilling for gas and oil that has been going on for years? What do we know about air pollution from the refining process for gasoline, diesel fuel and other forms of energy? There is no free lunch. Living is fraught with risks.

As we think about alternatives, we have much to learn. What happens when more and more people begin to handle cryogenic fuels such as LNG? Remember when only the gasoline filling station attendant by law could pump gasoline? Drivers were not allowed to pump their own fuel. Today with few exceptions, we fuel our own cars. Similarly, as we think about electric vehicles and electric charging stations, how much does the public, as well as commercial vehicle operators, understand about 110, 220 and 440 volt systems? What about vehicles driving with tanks of compressed fuels such as CNG? Is that a greater risk than a similar amount of BTUs of energy held in a thin walled tank of gasoline and/or diesel fuel? What about if there is an accident? Natural gas vents up to the atmosphere while gasoline and diesel fuel fall down to the ground at the accident scene. Which is better, assuming that at some point there will be an accident? What about electric power in battery powered vehicles? Haven’t some of the vehicles caught fire unrelated to an accident?

What about all of the people who heat their homes and/or cook with natural gas? Are they taking unreasonable risks?
When we consider alternatives, we are evaluating one set of risks with another. Shouldn’t we start considering hydrogen for fuel as it comes from water, the most abundant element on the planet? We can start by extracting the H from H₂O to get an abundant fuel. But, to do so we need to burn natural gas to make superheated steam to crack the molecule to get the hydrogen from the H₂O. How energy efficient is that?

Why not use electric power for commercial vehicles, particularly line haul trucks? The immediate problem is that one can’t get the power density required with electric vehicles to power today’s commercial vehicles. We needed the power of the internal combustion engine burning some type of fuel to get the power and speed of today’s modern commercial vehicles. From where would the power come to charge future batteries if there were some technology breakthroughs? Would we use coal, natural gas, or hydroelectric power?

Each alternative has costs to be considered in use as well as the costs incurred to bring it to market. For the foreseeable future, natural gas appears to be the most promising alternative fuel to diesel. Although it has existed a long time, what makes the use of natural gas an easy one as a replacement for diesel fuel is that in recent years it has been found in abundance due frac’ing technology. No other alternative has offered the logical choice of natural gas.
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Chapter 6: TRUCKER SURVEYS AND INDUSTRY PANEL INTERVIEWS

Trucker Surveys ............................................................... 96-102
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TRUCKER SURVEYS

Background: In addition to in-depth discussions with our 14 company panel discussed in the following section, we e-mailed several thousand questionnaires to fleets and owner operators to obtain more opinions. There were nearly 400 responses, 294 owner operators and 102 fleets (see graph below). Because owner operators and fleets are very different with respect to new truck purchases, we analyzed these responses separately where appropriate. Moreover, although many owner operators do not buy new vehicles, we thought it important to seek the opinions of the people behind the wheel.

Note: While the responses to these questions provide valuable insights, we are not extrapolating from these respondents’ opinions to the opinions of the entire industry.
Respondents were overwhelming in short and long haul operations, as shown in the following graph.

The following graph indicates the length of haul of the two respondent groups.
The number of tractors operated by fleets is displayed in the following graph.

The final demographic graph indicates the annual revenues of fleets.
Responses:

- About 45 of 85 fleets responding to this question indicated an average knowledge (discussed with knowledgeable people/attended seminars) or above average knowledge (talked in detail with vendors) of NG; only 50 of 290 owner operators thought they were at these levels.
- About half of our 102 fleet respondents will consider purchasing an NG vehicle or are evaluating the viability of the NG engines in the near future.
- Slightly more than half of the 80 line haul fleets are considering NG.
- The shorter the haul of our respondents, the more likely they were to indicate they would consider NG.
- Around 80% of our nearly 300 owner operators answered no to questions concerning NG adoption and evaluation.
  - It is somewhat surprising that nearly 20% of our owner operators indicated they would consider NG. This hints at a substantial breadth of NG discussions among drivers.
- In answering questions concerning the hurdles to adopting NG:
  - 90% of fleet respondents and 80% of owner operators, about 340 of 400 total respondents, are concerned about fueling station availability.
  - Nearly all the fleet respondents and 70% of owner operators were concerned about NG vehicle pricing.
  - Product specs and performance were concerns for about 50% of fleets and 70% of owner operators.
  - Half of the fleet respondents and a third of the owner operators listed secondary market value as a concern.
  - When asked how many NG vehicles would need to be domiciled at a location before a fleet would install their own fueling station, there were a wide variety of responses. This indicates many fleets are thinking about this question but perhaps they had not done detailed analysis. 11 of the 38 responding fleets did indicate they would require 20 or 25 vehicle, with an additional 8 indicating they would require 50 or 100 vehicles.
Responding fleets were evenly split on the question of whether they would specify CNG vs. LNG.

Of our responding fleets, 58 of 100 fleets anticipate they will be between 0 and 15% natural gas in 5 years, with 33 of these fleets anticipating 5% or less. The Pareto chart below displays the complete results.
The overwhelming majority of responding fleets indicated a required 1 to 2 year payback. Fleet respondents indicated by a margin of 2 to 1 that long term pricing of NG contracts would facilitate their decisions.
Other Comments: Below are a few other phrases and comments from respondents:

- Several used the term “chicken and the egg”
- Lease terms need to be attractive
- [Government] subsidies would help
- People do not want to be pioneers
- Reduction in payload due to weight increases (mentioned several times)
- Cost to retrofit shops is a concern
- Unknown life and torque of NG engines
- Need to see proven reliability
- Family based trucking companies need to be sure of the return
- Want NG fueling stations as plentiful as diesel
- Payback is irrelevant if you don’t have supply
- We have run the NG numbers and NG does not make sense
- Constant refueling is a productivity killer, especially with HOS
- Vehicle mounted refueling is an option for some fleets
- Dual fuel is the best of both worlds
- Several respondents already have natural gas vehicles

Specs and performance are a concern to some.
- Secondary market prices are also a concern.
- Both CNG and LNG will probably be considered by purchasers. Perhaps it is too early in the process for well formed opinions.
- NG is a topic of sometimes heated discussion among drivers and fleet management. Owner operators admit to not being knowledgeable about NG. While many fleets that responded indicated they had average or above average knowledge, there is a great deal of room for increased understanding. The fact owner operators are considering/evaluating NG demonstrates great interest among drivers.
- There is a deep seated concern among some truck drivers about driving NG vehicles. Safety is definitely a concern. Performance may be another. If the feelings of some truckers expressed in phrases like “[I] Will not drive a rolling bomb” or “I’ll Collect a Welfare Check [before driving a NG vehicle],” are at all reflective of even a sizeable minority of drivers, trucking firms with NG vehicles may have to engage in considerable education, selling, and perhaps even inducing drivers. Engine companies and vehicle OEMs might engage in marketing/co-marketing efforts to the driver community, such as family “ride and drive” events. Promotion of long term price guaranteed NG may encourage adoption.
- Fleets will definitely consider on-site NG fueling.
- Most of our fleet respondents indicated that in 5 years their fleets would be 15% or less NG.
  - At first look this might suggest that ACT 2017 forecast may be too high. However, reviewing the detail behind the forecast indicates the survey results are not inconsistent with ACT’s projected shares for TL, LTL, and private fleets.
PANEL INTERVIEW RESULTS

ACT interviewed representatives from fleets (for hire and private), leasing firms, finance companies, and component suppliers over three weeks in July 2012. Each person was asked a series of 15 questions and the summarized results, many in the respondent’s own words, are listed in the following pages. Some answers may not be factual, but we included all points of view because those statements are believed true by the panelist interviewed. Question 15 is addressed in Chapter 8, “Conclusion and Discussion of Industry Questions.”

QUESTION 1: If the increased weight of CNG or LNG tanks for natural gas reduced your payload, what payload loss would cause you to not choose CNG/LNG?

- 0 lbs to 100 lbs or even 1000 lbs
- Bulk haulers who weigh out were more sensitive to increased weight than those who cube out. Bulk haulers don’t want any payload loss at all; it is too important to them.
- Cube out loads don’t have a problem adding heavier natural gas tanks to the point that they gross out, then it becomes a large concern.
- Other factors included how many tanks you need to use and the mileage range you want.
- One respondent thought going away from diesel would eliminate diesel aftertreatment weight, but mentioned that would have to be tempered against the additional weight of the natural gas tanks.

QUESTION 2: Do you foresee “green” customers giving any preference to NG equipped fleets and if so what preference?

The majority of respondents said yes because:

- Sustainability is good for publicity.
- Customers have enough data that they are driving the conversion process based on sustainability data alone.
- Lower emissions are associated with NG and customers may like the idea of NG being of local resource.
- It helps the U.S. economy and reduces dependence on foreign oil.

Negative or undecided comments included:

- One panelist said that on his/her side of the business, no, not right now. They would go with it as a customer if they saw the option with all other things being equal.
- Customers prefer natural gas, but this is partly based on the misconception that NG is that much greener. As customers become more educated, they will discover there isn’t much advantage to NG environmentally.
- Customers have been exposed to the virtues of NG, but they aren’t doing research for themselves or taking into account costs of equipment, retrofitting shops, etc., while expecting their rates to decline immediately.
- Going green is good only if the price is comparable.

QUESTION 3: Do you foresee shippers wanting pass-through of cost savings in freight rates? If you are a shipper, would you want the cost savings of NG passed to you?

- Definitely. I think one of the things we as a shipper are cognizant of is incremental costs of equipment. We are talking about how we can share expenses as technology is becoming more widely used.
- Carriers need to recoup costs before sharing costs with customers.
- We are trucking company and shipper both. This is a difficult question to answer. I’m sure if we went to NG we’d probably have two sets of fuel surcharges for diesel and NG; however, we do have initial higher cost for NG vehicle. Would make that argument to customer in the beginning.
- Yes, we’d like to see some pass through, but we understand that the technology has to be paid for first.
- One critical element is to eliminate fuel surcharges and/or have fuel cost price stability.
- It will be up to companies to educate their customers that fuel savings will be used to offset additional upfront expenditures. Anticipate showing vehicle expense to customers to explain why savings, at least in first couple years, is not being passed along.
- Most customers want the green image and the cost savings.
Things are evolving rapidly and we can't just focus on incremental fuel savings; we have to focus on all aspects.

Customers don't care about upfront costs; they are concerned with fuel surcharges.

**QUESTION 4:** What do you consider your current diesel life cycle in years before trading for new equipment?

- 5 - 7 yrs; up to 10 yrs; as little as 3 yrs. with 2 drivers
- Highly dependent on mileage the tractor is being used and on how the vehicle is being used, i.e. team operations, etc.

4b: If you have investigated natural gas powered equipment, what do you project your life cycle cost savings to be for a similar life cycle?

- $50,000 - $60,000; ROI $1.25
- More information is needed to determine an answer. How do you answer without knowing true savings between the fuels or whether an offset from the government will be available? One dependent factor includes vehicle markup, which is different from LNG to CNG to classes per vehicle to pricing of fuels.
- These are the things we are still looking into. We feel we are now losing money on our 5 LNG trucks After about a year, we have yet to see where that breakeven will be. We are paying more for fuel than we thought we would and the trucks are expensive.
- If driven greater than 70k miles, you will see cost of fuel differential over 6-7 year timeframe. Assuming $1.50 per DGE cost savings + 6 mpg, then the breakeven point is 70k miles.
- For leased equipment, the initial cost is baked into lease payments; so, customers immediately see a cost savings based on fuel price.
- As the fuel price gap gets bigger or the application changes, savings change. Factors to consider include: equipment price, availability of fuel, and differential of fuel. We're trying to build an ROI model that is not as fluid as it is today.
- Savings comes from fuel cost differential and we haven't seen it materialize in operating costs or in maintenance because have so little information and the deployed vehicles have only had for 1.5 years, not a full life cycle. Until we get more data, we're not ready to say maintenance or operating costs change, outside of fuel differential.
- There has been a lot of experience with smaller applications, but not much with heavier vehicles.

**QUESTION 5:** What is your estimated time for fueling diesel powered equipment (add fuel, check oil, antifreeze, DEF, etc.)?

- The typical answer was 10-20 minutes, with 8 minutes on the low side and 30 minutes on the high side.

5b: Would you anticipate your natural gas fueling time to be more or less? And how much more or less?

- The typical answer was 10-25 minutes, with the high side from 35-60 minutes, depending on the age of the CNG fueling equipment.
- Some expected not much change; it would be about the same as diesel. CNG will be slower than LNG but all are dependent on having good up-to-date equipment at fueling stations.
- Some stated concern about drivers' HOS and extended fueling times.

**QUESTION 6:** Would you consider converting present diesels to natural gas (at engine overhaul time)?

- Most panelist firms said no, stating that they do not keep vehicles long enough to do rebuilds.
- Some noted that as more production engines are made available from OEMs, they will buy from the OEM rather than convert.
- Long-time customers of (one OEM) don't want to buy new NG vehicles; they are going to conversions and adding tanks.

6b: If so, what premium might you pay including natural gas fuel tank costs?

- $35-45,000
- Some respondents were unsure citing conversion costs unknowns and dependence on life cycle of NG tanks in on-highway applications.
QUESTION 7: By 2017, what percentage of new North America Class 8 trucks purchased will be natural gas?

The following shows the three response ranges received during the interviews for all except specialty operations, which produced no consistency separation:

- TL (short haul): 1-2%; 5-10%; 20-50%
- TL (long haul): 1-2%; 5-10%; 20-50%
- LTL (short haul): 1-2%; 5-10%; 20-50%
- LTL (long haul): 1-2%; 5-10%; 20-50%
- Route Delivery: 1-2%; 5-10%; 20-50%
- Specialty Operations: 5-75%

(Refuse, Dump, Mixer, Service, Etc.)

- Divergent opinions: Panelists with knowledge of natural gas as a transportation fuel forecast 20-50% for Class 8 TL and LTL while those knowing less about the fuel suggested 5-10%; only a few believed it would be 1-2%.
- One large fleet projected < 5% for TL and 40% for LTL.
- Most all respondents estimated larger penetration of NG for Route Delivery and Refuse, including other specialty operations.
- Leasing and finance companies forecasted TL and LTL in the 5-10% range.
- Nearly all those interviewed noted that major government regulations, taxes, incentives, and fueling infrastructure could have a significant impact on the adoption rate of new natural gas fueled vehicles between now and 2017.

QUESTION 8: What are the drivers for your interest in natural gas vehicles? Check all that apply.

- Customer requirements: 9 out of 14
- Internal sustainability or green goals: 10 out of 14
- Reduced operating costs/Higher profits: 13 out of 14
- Reduced reliance on foreign oil: 9 out of 14
- Other. Please explain.

- As we look at NG we can lock in fuel prices for 10 years on the futures market, but can’t see that on oil.
- There is much publicity and transportation teams are being asked to investigate NG options.
- One panelist noted that some companies are so focused on green that if it is close, they will go green. S/he added that other companies are more economically focused and to go green, it would have to be more than close.
- Another respondent commented that his/her firm is waiting on technology and infrastructure for a better understanding of true costs.

QUESTION 9: What are your ROI requirements to purchase NG vehicle?

- Most said 18-24 months.
- Some said as long as 36 months.
- Those interviewed believed ROI should be the same as diesel, or a little better. Most expectations were based on no additional residual value for NG equipment over lower priced diesel equipment.

QUESTION 10: Do you foresee any problems financing natural gas powered vehicles?

- 7 No; 4 Yes
- I don’t think so. We had one bank question it, but another was willing to do it.
- Finance companies need a better understanding of technology and future secondary market valuations before they will feel comfortable.
- Establishing residual rates with lease companies is very important. Equipment and NG has got to be sustainable on its own. Today savings on fuel is being taken up with accessory expenses. As a lessor, part of the deal is rate at end of lease. If the residual is set too high then the monthly payments are too low and there is money due at the end of the lease. If the residual is set too low then the monthly payments will be too high and there will be money due back at the end of the lease (not all of the money may be recoverable). They are looking out 7 years to determine what leased equipment is really going to be worth. This is getting more difficult with all sustainability platforms including electric, natural gas, and hybrids. Technology is going
to change 10-fold before equipment is gotten rid of; how will that effect rates.
- The resale market has not yet been established. Tanks have no resale value (yet). We think tank technology will evolve rapidly. Tanks are being written off in liquidation. I think those tanks have value and will have a market, but the financial and banking market doesn’t think there is a value.

**QUESTION 11:** How close would the fuel cost savings differential have to be for you to stay with diesel?
- Generally, 25% fuel cost delta is the number.
- 25% based upon trade-offs. The driver frustration factor needs discussed. This will take drivers off their normal routes; you have to have a strong economic situation to tolerate driver dissatisfaction in a market where drivers are already had to come by. If diesel is $4 and you’re not saving more than $1 per gallon, the frustration/hassle wouldn’t be worth it.

**QUESTION 12:** Are you aware of the on-trailer natural gas storage proposal by Kogel (gas cylinders on the trailer) and, if so, what are your thoughts about the proposal?
- Most of those interviewed were not aware and most would not use the tank on trailer option.
- If a fleet cubes out, this proposal could be acceptable, but the problem of fleets using 2-3 trailers per tractor still exists.

**QUESTION 13:** If considering natural gas is not your number one cost-reduction consideration right now, what is?
- Optimizing order points to minimize miles.
- Overall optimization of the way we move merchandise.
- Right now, we are upgrading tractors and trailers with automated transmission, trying to take the driver out of the fuel economy equation.
- A lot of customers are going after NG.
- Procurement: taking advantage of larger scale buys.
- Aerodynamics, transition redesigns, idle management, but still a lot of money for engineering of these things.
- Driver training, continuing to raise the bar with the bottom 10% of drivers, as drivers can have 30-35% impact on fuel economy.
- Improving the fuel efficiency of diesel.

**QUESTION 14:** Is there anything else about natural gas as a fuel for heavy duty vehicles that you would like to tell us?
- CNG is preferred because we believe Clean Energy (corp.) will create a monopolistic pricing environment for LNG.
- It is scary to embark into new territory. What if we invest in the technology and change our processes (go out of our way for the fuel) and it does NOT pay off? What if there is no ROI but actually an expense?
- Fueling infrastructure: Fueling range is the biggest concern. Respondents don’t want to have 4-5 tanks on the side of their vehicles without the range, whether daycab or over-the-road. That’s the paradox: The guys running the most miles get fastest return, but also the guys that have to put on the most tanks to run the largest miles.
- It is taking $350-400k per shot to update shops to meet compliance. Also, there is need to train personnel, including back office staff (like accounting), as well as drivers and shop personnel for handling differences that NG creates. Training is needed to get people to understand characteristics of NG. For example, welding, smoking, and doing electrical work near natural gas and NG fueled vehicles. It is stable and safe, but conditions exist that poor decisions could be fatal.
Chapter 7: ACT’S NG VEHICLE PENETRATION FORECASTS AND CALCULATORS

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Natural Gas Adoption as a Class 8 Fuel of Choice

**Forces For Change**

- Total Fuel Cost Per Mile
- Long Term Oil/Diesel Prices
- Price Stability (Pump Price Insensitive to NG Spot Prices)
- Energy Independence
- Recent Major Engine and OEM Vehicle Product Announcements
- 80% ENGINE Part Commonality with Diesel
- No Aftertreatment (No SCR System, No DEF Additive)
- Infrastructure Investments & Announcements (Clean Energy, Trillium, and Shell)
- Sustainability Commitment (& Green Marketing)

**Forces Against Change**

- Energy Content
- Engine Efficiency
- LNG/CNG Tank Cost
- Range
- Few Product Offerings
- LNG Handling (Cryogenic)
- Training (Drivers, Technicians, Sales, Marketing, Accounting, HR, etc.)
- Major Investment to Bring Repair Facilities Up to Codes
- Little Refueling Infrastructure
- Uncertain Truck Residual Value

**Environmental: Combustion Advantage:** Least CO$_2$ of fossil fuels

*The radiative forcing (heat trapping ability) of methane is many times that of CO$_2$; however, CO$_2$ lasts many times longer in the atmosphere.*
INTRODUCTION

In ACT’s hypothesis, it was suggested that a fundamental change was on the horizon and the commercial vehicle industry would see an increase in the use of natural gas as a fuel of choice to power heavy duty and medium duty trucks. The question becomes, “will the industry change and how fast will the change occur?”

Anytime change occurs, there must be motivation for the change, either legislated action or independent motivation. For independent change to occur there must be an ability and benefit to change. The change to natural gas as a fuel for heavy duty and medium duty trucks implies:

- Product availability of natural gas engines
- OEM availability of natural gas fueled trucks.
- Industry service support
- Natural gas fueling station proliferation

If one believes these are the elements for change, we can use these facts to form a conclusion.
SNAPSHOT OF IMPORTANT NATURAL GAS VEHICLE CHARACTERISTICS

Disclaimer: These estimates are based on current offerings as of July 2012 with expectations they will change. We expect that NG vehicle costs will decline over time along with the weight penalty for CNG or LNG applications. It is important to remember that only about 35% of Class 8 trucks weight out. The remaining 65% cube out.

NG Engine Options:

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<tr>
<th></th>
<th>2012</th>
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<tr>
<td>TODAY</td>
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<tr>
<td>SING (Spark)</td>
<td>8.9L CW</td>
<td>8.9L CW</td>
<td>8.9L CW</td>
</tr>
<tr>
<td>PING (Dual Fuel)</td>
<td>15.0L WI</td>
<td>15.0L WI</td>
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FUTURE (NEW)

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<td>SING (Spark)</td>
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<td>11.9L CW</td>
<td>15.0L C</td>
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<tr>
<td>PING (Dual Fuel)</td>
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<td>13.0L N</td>
<td>13.0L N</td>
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<tr>
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<td></td>
<td>13.0L V</td>
<td>13.0L V</td>
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</tbody>
</table>

For a discussion of SING or PING, see page 48.

Vehicle Options (estimates) with NG Fuel:

- Class 8 tractor using LNG with 160 DGE (2 tanks) will add over 1000 lbs of extra weight compared to diesel and have a range of about 800 miles.
- Class 8 tractor using CNG with 140 DGE (5 tanks) will add over 2000 lbs of extra weight compared to diesel with a range of 600-700 miles.
- Class 8 tractors will be available with a wide variety of engine options using CNG or LNG, both spark ignited or dual fuel. The number of NG tanks will determine the DGE capacity, and therefore, the mileage before refueling. Extra weight and mileage range (DGE) will vary depending on SING or PING technology and the amount of DGE storage capacity. The curb weight of the installation ultimately will depend upon the fueling option chosen, SING or PING, and the DGE fuel capacity (mileage) needed.

Vehicle Cost Premiums:

- Depending on engine and fuel capacity options, the NG truck today has a reported cost premium of $30,000 to $50,000 for SING technology (spark ignited). This assumes today’s offerings for engines, tanks, and fuels (CNG, LNG).
- Dual fuel (PING) 15L premiums are reported to be $80,000 to $100,000.

Fueling Station:

- Reported 900 CNG stations in the U.S., but the majority are focused on automobiles and pickups. Maybe as many as 100 to 200 can support commercial vehicles today and 50 to 100 for LNG.
- Current fast fill CNG and LNG stations will have fill times close to diesel with LNG being the fastest. CNG slow fill is currently not an option for over-the-road, long haul applications.
- The range of today’s NG vehicles is potentially shorter than diesel, so long haul trucks will require specific knowledge of where NG fuel stops are located and plan accordingly.

Fuel type Options:

- CNG and LNG (SING, PING)
- DME (Dimethyl Ether) may be a viable fuel option in the future, but not this decade.

Fuel Tank Options:

- Manufacturers are working on more application friendly and potentially lighter, less expensive tanks. Volume production is a key variable.
- A fuel tank example is shown on the next page. It is an Isuzu MD Utilimaster truck that includes 2 Type 1 CNG tanks, 16”x60”, with 27 GGE (gasoline gallon equivalents) that added 674 lbs. to the GVW. The stated range is 200 to 224 miles. Two other CNG Type 4 tank examples are described.
SPECIFICATIONS

TANK OPTIONS
Option 1: (2) 16” Diameter x 60” Length, Type 1 tanks
27 GGE Total Capacity (200-225 miles)
Net Weight Adder: 674 lbs.

Option 2: (2) 18” Diameter x 60” Length, Type 4 tanks
31 GGE Total Capacity (225-250 miles)
Net Weight Adder: 290 lbs.

Option 3: (2) 18” Diameter x 78” Length, Type 4 tanks
42 GGE Total Capacity (300-325 miles)
Net Weight Adder: 290 lbs.
Available on chassis with greater than 150” WB

Standard tank location shown: subject to change based on vocational application and selected tank option.

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CHARLOTTE MODIFICATION CENTER
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Charlotte, MI 48813
PRODUCT AVAILABILITY

The development and introduction of an internal combustion engine is really the science of compromise. As an engineer designs a new engine and production engineers think about how to mass produce the engine, a number of design questions need to be addressed: How much power and torque will be developed? How much will the engine weigh? What are the reliability and durability targets? What emission characteristics will the engine exhibit? What type of fuel(s) will the engine use? The list is not exhaustive; new elements get added all the time and the weight of each element can change over time.

Regardless of what any design engineer might think, the end customer will set priorities of what is expected. Engine design and development engineers have always tried to prioritize commercial vehicle engines in line with customers' expectations.

Since an internal combustion engine is nothing more than an energy converter and customers prioritize how they want an engine to perform, engine manufacturer resources devoted to the design and development of engines were allocated along the lines of what product was selling. Work on diesel fueled engines was primary choice and natural gas was secondary, if that.

Fortunately for natural gas engine development, paths have been similar. The lion's share of the design work that goes into the development of a diesel engine applies to what is needed for a natural gas engine.

Natural gas engines can be manufactured in existing manufacturing plants. The same technicians that service today's diesel engines can use the same diagnostic tools to find most problems and make repairs. Further, it is not an either/or choice; manufacturers can build both types and change build rates in line with demand.

Since an internal combustion engine is the end result of the science of compromise, the compromise can easily shift to the production of natural gas fueled engines for commercial trucks in a reasonable amount of time. There are no show stoppers here. What does the customer want? Fortunately for the truck assembler, natural gas engines are similar to today's diesels and install in the same engine space as a diesel.

Natural gas and diesel engines are so similar in design and manufacture that in the long run, engine manufacturers can shift build to either product over the short and long run without major revisions to their respective production processes.

How fast production will shift remains to be seen. One obstacle will be the number of natural gas engine test cells. Too few test cells has hampered production in the past.

What is unknown as of this writing is how fast the engine manufacturers can increase production rates of new natural gas engine models. For some, the implication is new natural gas engines in new production plants. Manufacturers have been known to restrict initial supplies as they monitored initial quality before raising production.

For 2013, the production increase by natural gas engine suppliers and OEM truck manufacturers might match the pace of new fueling stations and there will not be a bottleneck in supply and demand.

TRUCK OEM NATURAL GAS FUELED ENGINE AVAILABILITY: As we began the 21st century, OEMs had few natural gas powered offerings. A new, natural gas engine could be delivered in Freightliner, Autocar or Crane Carrier trucks. The Autocar and Crane Carrier offerings were aimed at the refuse truck market. The vehicles were equipped, for the most part, with CNG tanks. The purchase of the vehicles was subsidized by grants aimed at cleaning the environment. The emission characteristics of the natural gas engines powering these vehicles were substantially better than diesel engines of the time, and were the primary reason the natural gas vehicles were purchased. The topics of the day were “where can I purchase fuel and/or what will it cost me to own and operate my own natural gas fueling station?”

2012 is very different than 2001. With Navistar's recent announcements, essentially every OEM now offers a natural gas powered truck. For some, such as the refuse industry trucks, the percentage of natural gas powered trucks sold is high and increasing. Refuse truck NG penetration is presently around 40%, but is expected to rise to close to 100% within 5 years. The choice of natural gas engine suppliers will be multiple: Cummins Westport, Westport Innovation, Navistar and Volvo in 2013, as well as Cummins Inc. in 2014. The
natural gas engines will be built on multiple diesel engine platforms and will come in a variety of horsepower and torque ratings.

Why the change? Customer demand is the answer. Meeting the 2010 emission legislation with a diesel came with additional customer costs both in the form of higher acquisition costs and operating costs over the life of the vehicle.

Two forces were at work. The public wanted clean air, but given the amount of fuel burned in a truck over its lifetime, the customer wanted operating efficiencies. As new natural gas engine platforms are introduced with higher ratings of horsepower and torque, the theoretical discussions about engine efficiencies will give way to demonstrations of performance. Customers will ask for complete cost comparisons including fueling costs when comparing diesels with natural gas power.

In 2001, you could get 280 horsepower from a typical spark ignited natural gas engine or 450 horsepower plus from a natural gas HPDI engine. Yesterday's 280 horsepower spark ignited natural gas engine gave way to 320 horsepower and 1,000 lb. ft. of torque. For 2013, more power, torque and features not previously offered have been announced. In short, more customer horsepower and torque requirements can be met with soon-to-be available engines. Engine suppliers are betting customers want the option. No OEM wants to leave a large customer segment without some type of natural gas product offering.

It would appear that OEMs believe the market for natural gas powered vehicles is growing, and they plan on having product offerings and participating in the market. That means having appropriate product available, knowledgeable sales staff, appropriate service support including customer training, and a positive “pro gas” mentality. A summary of current offerings, as well as anticipated products, follows:
### Table 7.1

<table>
<thead>
<tr>
<th>MAKE</th>
<th>MODEL</th>
<th>ENGINE</th>
<th>GVW</th>
<th>HORSEPOWER</th>
<th>TORQUE</th>
<th>LNG (DGE)</th>
<th>CNG (DGE)</th>
<th>CLASS</th>
<th>SOURCE</th>
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<tr>
<td>Autocar</td>
<td>LCF REFUSE Hauler</td>
<td>CUMMINS ISL-G</td>
<td>320 HP</td>
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<td>CNG 8</td>
<td>up to 150 miles w 2 tanks &amp; 275 miles w 4 tanks</td>
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<td>Freightliner</td>
<td>Cascadia 113</td>
<td>Cummins Westport ISX12 G (year 2013)</td>
<td>up to 60,600 lbs</td>
<td>400 HP</td>
<td>1,450 lb-ft</td>
<td>168</td>
<td>155</td>
<td>8</td>
<td><a href="http://www.freightlinertrucks.com/trucks/Alternative-Power">www.freightlinertrucks.com/trucks/Alternative-Power</a>, Trucks/Natural-Gas</td>
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<td></td>
<td>M2</td>
<td>Cummins Westport ISL G</td>
<td>62-1000 HP</td>
<td>660-1,000 lb-ft</td>
<td>65 and 86</td>
<td>60 and 75</td>
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<td>Isuzu</td>
<td>SAVANA Cargo Van</td>
<td>GMC SL V8</td>
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<td></td>
<td></td>
<td></td>
<td>CNG 2/3</td>
<td>up to 200 miles w 3 tanks &amp; up to 300 miles w 4 tanks</td>
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<td>International</td>
<td>Workstar CNG</td>
<td>ISL 7.6L</td>
<td>27,500-72,000 lbs</td>
<td>520-860 HP</td>
<td>860 lb-ft</td>
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<td></td>
<td>Prostar LNG (late 2013)</td>
<td>Dual Fuel MaxxForce 13 NG</td>
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<td>V900</td>
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<td>63-160 or more</td>
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<td>Cummins Westport ISL G</td>
<td>69-139</td>
<td>69-139</td>
<td>8</td>
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<td>120</td>
<td>Cummins Westport ISL G</td>
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<td>132</td>
<td>Cummins Westport ISL G</td>
<td>up to 66,600 lbs</td>
<td>69-139</td>
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<td></td>
<td>386 LNG</td>
<td>Cummins ISX</td>
<td>430 HP</td>
<td>1,750 lb-ft</td>
<td>40-114</td>
<td>8</td>
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</table>
AFTERMARKET NG CONVERSIONS

While not specifically addressed in this report, the impact of natural gas conversions deserves a brief mention. These initial conversions helped provide the natural gas engine experience to the market, an important “proof of concept” for early adopters as well as truck OEMs. This early low volume activity, while market-niche oriented, helped set a foundation for on-road usage of natural gas fueled vehicles in the U.S.

Some of these systems could be ordered through a dealership as a modification when ordering a new vehicle. They could also be purchased separately to modify new or used vehicles.

The attached tables list vendors providing these systems. All systems shown were certified either by the EPA or CARB (California Air Resources Board).

Worth noting:

- Many more vendors provide gasoline or gasoline/E85 engine conversions than diesel conversions.
- Of the 18 companies that have provided gasoline conversions, only 9 remain active with certified conversions for 2012MY.
- Note that diesel engine conversions were available well before gasoline conversions; American Power Group offered their products beginning with 1998MY.
- Diesel engine conversions only apply to 2009MY and earlier engines. The advent of 2010 EPA regulations are likely the cause of the end of aftermarket diesel conversions. The impact of OEMs providing these alternate fuel vehicles in their regular product line has also negatively impacted the aftermarket.

Two reference tables can be found on the following pages. The first provides contact information for the 22 companies that have served, or are currently serving, the aftermarket with EPA or CARB certified conversions. The second categorizes those companies into gas or diesel groups. That matrix also shows the OEMs whose vehicles were being converted, along with the model years that have been certified. The tables are a high level summary of the full document available on the NGVAmerica website as of 08/06/2012. That document includes more details regarding engine sizes and vehicle models being converted, along with the certification references for the EPA or CARB, and is updated on a regular basis. It can be found at:

http://www.ngvamerica.org/about_ngv/available_ngv.html
TABLE 7.2

<table>
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<tr>
<th>Company</th>
<th>Address</th>
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<th>Contact</th>
<th>Phone</th>
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<tr>
<td>Altech_Eco</td>
<td>101 Fair Oaks Road</td>
<td>Arden</td>
<td>NC</td>
<td>28407</td>
<td>USA</td>
<td>Mike Cerven</td>
<td>842-654-8300</td>
<td><a href="mailto:mikecervan@alttecheco.com">mikecervan@alttecheco.com</a></td>
<td><a href="http://www.alttecheco.com">www.alttecheco.com</a></td>
</tr>
<tr>
<td>American Alternate Fuel</td>
<td>2503 Poplar Street</td>
<td>Algona</td>
<td>IA</td>
<td>50511</td>
<td>USA</td>
<td>Ed Wolf</td>
<td>515-395-1360</td>
<td><a href="mailto:ewolf@americanpowergroupinc.com">ewolf@americanpowergroupinc.com</a></td>
<td><a href="http://www.americanpowergrouping.com">www.americanpowergrouping.com</a></td>
</tr>
<tr>
<td>Auto Gas America</td>
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<td></td>
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<td></td>
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<tr>
<td>BAF Technologies</td>
<td>2415 Beatrice Street</td>
<td>Dallas</td>
<td>TX</td>
<td>75208</td>
<td>USA</td>
<td>Brent Pope</td>
<td>866-931-8940</td>
<td><a href="mailto:bpope@baftechnologies.com">bpope@baftechnologies.com</a></td>
<td><a href="http://www.baftechnologies">www.baftechnologies</a></td>
</tr>
<tr>
<td>Clean Air Power, Inc.</td>
<td>13615 Stowe Drive</td>
<td>Poway</td>
<td>CA</td>
<td>92064</td>
<td>USA</td>
<td>Kevin Campbell</td>
<td>909-393-7933</td>
<td><a href="mailto:kcampbell@cleanairpower.com">kcampbell@cleanairpower.com</a></td>
<td><a href="http://www.cleanairpower.com">www.cleanairpower.com</a></td>
</tr>
<tr>
<td>CNG Store (dba Auto Gas Store)</td>
<td>1596 West 2650 s, Suite 103</td>
<td>Ogden</td>
<td>UT</td>
<td>84401</td>
<td>USA</td>
<td>Brent Pope</td>
<td>866-931-8940</td>
<td><a href="mailto:support@autogasamerica.com">support@autogasamerica.com</a></td>
<td><a href="http://www.autogasamerica.com">www.autogasamerica.com</a></td>
</tr>
<tr>
<td>EcoDual</td>
<td>601 Bay Street</td>
<td>Beaufort</td>
<td>SC</td>
<td>29902</td>
<td>USA</td>
<td>Doug Thomson</td>
<td>617-855-7999</td>
<td><a href="mailto:doug.thomson@ecodual.com">doug.thomson@ecodual.com</a></td>
<td><a href="http://www.ecodual.com">www.ecodual.com</a></td>
</tr>
<tr>
<td>Fuel-Tek Conversions Corp</td>
<td>5660 E 58th Avenue</td>
<td>Commerce City</td>
<td>CO</td>
<td>80022</td>
<td>USA</td>
<td></td>
<td>702-941-2791</td>
<td><a href="mailto:answers@fueltek.biz">answers@fueltek.biz</a></td>
<td><a href="http://www.fueltek.biz">www.fueltek.biz</a></td>
</tr>
<tr>
<td>Go Natural CNG</td>
<td>2023 South 625 West</td>
<td>Woods Cross</td>
<td>UT</td>
<td>84087</td>
<td>USA</td>
<td>Lucas Kjar</td>
<td>801-281-4766</td>
<td><a href="mailto:ljar@gonaturalcng.com">ljar@gonaturalcng.com</a></td>
<td><a href="http://www.gonaturalcng.com">www.gonaturalcng.com</a></td>
</tr>
<tr>
<td>Greenkraft Inc</td>
<td>2530 S. Birch Street</td>
<td>Santa Ana</td>
<td>CA</td>
<td>92707</td>
<td>USA</td>
<td>Sos Bardakjian</td>
<td>714-545-7777</td>
<td><a href="mailto:sosi@greenkraftinc.com">sosi@greenkraftinc.com</a></td>
<td><a href="http://www.greenkraftinc.com">www.greenkraftinc.com</a></td>
</tr>
<tr>
<td>High Pressure Group</td>
<td>1468 James Road</td>
<td>Garnerville</td>
<td>NV</td>
<td>89460</td>
<td>USA</td>
<td>Trent Colbert</td>
<td>775-455-4059</td>
<td><a href="mailto:info@highpressuregroup.com">info@highpressuregroup.com</a></td>
<td><a href="http://www.highpressuregroup.com">www.highpressuregroup.com</a></td>
</tr>
<tr>
<td>IMPCO Automotive/Evotek</td>
<td>1274 South State Road 32</td>
<td>Union City</td>
<td>IN</td>
<td>47390</td>
<td>USA</td>
<td>Beverly Osborne</td>
<td>765-305-2091</td>
<td><a href="mailto:Bosborne@impcautomotive.com">Bosborne@impcautomotive.com</a></td>
<td><a href="http://www.impcautomotive.com">www.impcautomotive.com</a></td>
</tr>
<tr>
<td>Landi Renzo USA/Baytech</td>
<td>23535 Talo Avenue</td>
<td>Torrence</td>
<td>CA</td>
<td>90505</td>
<td>USA</td>
<td>Gianluca Maso</td>
<td>310-283-8661</td>
<td><a href="mailto:maso@landiusa.com">maso@landiusa.com</a></td>
<td><a href="http://www.landiusa.com">www.landiusa.com</a></td>
</tr>
<tr>
<td>NatGasCar</td>
<td>17000 St. Clair Ave</td>
<td>Cleveland</td>
<td>OH</td>
<td>44110</td>
<td>USA</td>
<td>Joe Wray</td>
<td>216-692-3700</td>
<td><a href="mailto:jwray@natgascar.com">jwray@natgascar.com</a></td>
<td><a href="http://www.natgascar.com">www.natgascar.com</a></td>
</tr>
<tr>
<td>Naturaldrive Partners</td>
<td>13765 W Auto Drive #122</td>
<td>Goodyear</td>
<td>AZ</td>
<td>85338</td>
<td>USA</td>
<td></td>
<td></td>
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<tr>
<td>NGV Motori/NGV Conversions, Inc.</td>
<td>5589 Callcott Way, Suite 1416</td>
<td>Alexandria</td>
<td>VA</td>
<td>22312</td>
<td>USA</td>
<td>Michelle Guzzone</td>
<td>866-636-2289</td>
<td><a href="mailto:michelle@ngvus.com">michelle@ngvus.com</a></td>
<td><a href="http://www.ngvus.com">www.ngvus.com</a></td>
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<tr>
<td>Parnell USA</td>
<td>1720 Deer Valley Rd #101</td>
<td>Phoenix</td>
<td>AZ</td>
<td>85024</td>
<td>USA</td>
<td></td>
<td>623-581-8335</td>
<td><a href="mailto:info@usealtfuels.com">info@usealtfuels.com</a></td>
<td><a href="http://www.usealtfuels.com">www.usealtfuels.com</a></td>
</tr>
<tr>
<td>Powerfuel CNG</td>
<td>650 NW 27th Avenue</td>
<td>Fort Lauderdale</td>
<td>FL</td>
<td>33311</td>
<td>USA</td>
<td></td>
<td>800-963-4375</td>
<td><a href="mailto:info@powerfuelcng.com">info@powerfuelcng.com</a></td>
<td><a href="http://www.powerfuelcng.com">www.powerfuelcng.com</a></td>
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<tr>
<td>Wise Gas, Inc.</td>
<td>P.O. Box 266774</td>
<td>Weston</td>
<td>FL</td>
<td>33326</td>
<td>USA</td>
<td>Sara Neal</td>
<td>954-636-4291</td>
<td><a href="mailto:sara@wisegasinc.com">sara@wisegasinc.com</a></td>
<td><a href="http://www.wisegasinc.com">www.wisegasinc.com</a></td>
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Source: NGVAmerica
For full detail by engine size and model, please see: http://www.ngvamerica.org/about_ngv/available_ngv.html

As of 8/6/2012
Table 7.3

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<th>Original Fuel</th>
<th>Company</th>
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<td>BAF Technologies</td>
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<tr>
<td></td>
<td>CNG Store (dba Auto Gas Store)</td>
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<td>Fuel-Tek Conversions Corp</td>
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<td></td>
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Source: NGVAmerica

For full detail by engine size and model, please see: [http://www.ngvamerica.org/about_ngv/available_ngv.html](http://www.ngvamerica.org/about_ngv/available_ngv.html)

As of 8/6/2012
INDUSTRY SERVICE SUPPORT

Natural gas powered trucks and buses have been around for some time in one form or another. Early adopters of natural gas have since moved to repeat purchases, and new first time purchasers have come into the marketplace. Engine suppliers are on successive iterations of basic designs and “new” engine models are being introduced in the months ahead. With each new engine platform, the engine distributors provide mandatory training on the diesel-only version and/or the diesel/natural gas version. As the natural gas truck or bus engine population has increased, more and more truck dealer and independent repair shop businesses ventured into supporting natural gas vehicle owners’ needs for problem diagnosis and repair, either because it was mandated by the engine distributor or, more importantly, because a customer base of business had been established. Large fleet users, on the other hand, made arrangements for their shops to become proficient in maintenance, repair, and overhaul of natural gas powered vehicles.

As the population of natural gas fueled trucks and buses increased, OEM dealers (as opposed to engine manufacturer distributors) increased their ability to support natural gas fueled vehicles. They had to support the customer or see the customer go elsewhere. Fortunately for the engine distributor and the OEM truck dealer, the initial natural gas populations of trucks and buses were scattered around the country and in concentrated areas.

The question, then, becomes what happens as the population of natural gas vehicles moves from “comes home every night” to one of operating across the U.S.? The answer is an orderly transition of vehicle support. If the market demand is there, services will be provided. Engine distributors and OEMs have a vested interest in seeing that support is provided. New populations of natural gas powered line haul trucks will be going into service and conversations will take place between new customers and distributors/dealers on where and how service support will be provided.

Remember when ULSD (Ultra Low Sulfur Diesel) or DEF (Diesel Exhaust Fluid) was introduced, fleets were concerned about its availability and troubleshooting procedures for the introduction of the 2010 emission certified engines. Availability of DEF and technician training turned out to be a “non-event.” The introduction was relatively trouble free.

Remember that approximately 80% of the NG engine is the same as the diesel. Service and repairs on the unique components of natural gas engines is what the servicing facilities will have to target. It is not as if service and repair facilities have to learn the ins and outs of a completely new form of power. In addition, the diagnostic skills of using a computer and diagnostic software have already been learned and put into practice with diesel engines. The process of applying those skills to the unique parts of a natural gas engine should be relatively straightforward.

Similarly, the technology of servicing spark ignited gasoline engines easily carries over to natural gas engines. The basic ignition systems of gasoline and natural gas engines (ignition coil over spark plug technology) are known to technicians. The background training is already in place.

What is different with the introduction of natural gas is that there is no mandatory date for introduction. Instead, customer demand will bring about an organic change. OEMs will be offering natural gas options with specific introduction dates and quantities available. The stage is set for an orderly introduction of additional natural gas engine models.
NATURAL GAS FUELING STATION PROLIFERATION: CHICKENS & EGGS!

Business schools teach basic marketing by outlining what has to happen when the product has two elements: the razor and the blade, the camera and the film, the automobile and the fuel it needs, the television and the TV stations. In each case, unless you can find a way to present the complete package, you won’t be very successful. Natural gas as a fuel is no exception. If there are no natural gas engines, there is no need to worry about fueling stations. If you have fueling stations, you need to be concerned about natural gas engine offerings, horsepower and torque ratings and, most importantly, OEM availability. In each case, all the required elements must be in place or individual efforts will fail.

There are big dollar bets being made that natural gas can become a transportation fuel. Local gas utilities have always been interested in selling natural gas for transportation as it is a natural expansion of the sale of natural gas for utilities. But how does a company that is probably a government regulated public utility invest the capital required to build a modern natural gas fueling station if the primary demand is not there? Can they justify the large expense for a fueling station when the population in their respective territories consists of a few environmentally clean transit buses, a few natural gas powered passenger cars driven by early adopters (but only a couple of tank fill ups per month) and a fleet of refuse trucks?

Enter the corporations willing to make a big bet on the future transition to natural gas fuels. Clean Energy Fuels, Inc. is one such company. They have made bets with investments in Westport Innovation, the supplier of direct injection natural gas engines, (and, in turn, the joint venture with Cummins Inc. in the Cummins Westport joint venture to sell spark ignited natural gas engines) and now with Navistar.

For the big investors such as Clean Energy Fuels, as well as all the CNG and LNG tank suppliers,
manufacturers of compressors and all the related components, the transition to natural gas powered commercial vehicles must seem agonizingly slow. It seems the fueling infrastructure has always been the holdup to a rapid conversion to natural gas. For the engine suppliers, it is easy to build natural gas or diesel engines. For the truck manufacturer, whether a natural gas engine or a diesel engine is placed in the truck is not dramatically different. But fueling stations are different. There are really no alternative uses for a natural gas pumping station. Either you have the required volume in sales to support the investment or you don’t. How many times can you be wrong in forecasting how many vehicles will be in a given territory using natural gas? Can you make it up in sales elsewhere where gas sales exceed expectations and are very profitable?

The ability of one or more companies to quickly increase the number of fueling stations across the U.S. will be a key driver in the change to a dramatic increase in the use of natural gas for commercial vehicles. Furthermore, the fueling stations and their location in the truck transportation lanes is absolutely key to expanding natural gas fuel usage beyond those vehicles that return home every night to the same location such as refuse trucks, transit buses, and school buses.

What is different this time is the price of natural gas fuel. The economics all favor adopting lower cost natural gas fuel for commercial vehicles.

The pace of natural gas becoming a main-line vehicle fuel is dependent upon both distribution and strategic placement of fueling facilities across the country. Distribution of natural gas is obviously well established, but not necessarily widely understood. The following is a brief overview of that infrastructure.

Existing pipeline “corridors” provide nationwide distribution, as shown in the diagram page 119. Keys to the distribution system are numerous “hubs,” or transfer points, arranged throughout the system, as identified by the Energy Information Administration in the graphic on the previous page.

The most significant hub in the entire distribution system is the “Henry Hub.” Located in southern Louisiana, it connects to four intrastate and nine
interstate pipelines owned by various public and private pipeline operators. The facility operates two compressor stations that can transport 1.8 billion cubic feet per day (Bcf/d).

The Henry Hub is the largest centralized point of natural gas transportation in the United States. In 1989, it was selected as the official delivery mechanism for the New York Mercantile Exchange (NYMEX) natural gas futures contracts, and has become the de-facto price standard for natural gas in the U.S.

Operated by Sabine Pipeline LLC, the graphic on page 120 depicts the operation of this major transfer point for natural gas.

Prices for both spot and future markets, set at the Henry Hub, are generally considered the primary prices for the U.S. natural gas market. Spot and future prices at the Henry Hub are denominated in $/MMBtu (US dollars per millions of British thermal units). While market prices at the wellhead and the burner tip are unregulated in the U.S., they are closely correlated to Henry Hub pricing. For a view of the Henry Hub location, see the graphic below.

The natural gas spot price was $3.18/MMBtu at the 7/25/2012 market close. Over the last 12 months, prices declined through mid-April to historic low levels before beginning to rebound. Natural gas prices now sit approximately 70% above those historic April lows.

The following chart depicts natural gas pricing over the last 10 years:

![Spot Natural Gas Prices: Henry Hub](image-url)

Source: EIA, ACT Research Co., LLC. Copyright 2012
NATURAL GAS REFUELING INFRASTRUCTURE

Information from the U.S. Department of Energy, Alternative Fuels Data Center (AFDC) identifies the following vehicle fueling infrastructure for CNG and LNG in the United States as of 7/23/2012:

CNG Fueling Infrastructure

1,066 active CNG refueling locations
- 566 privately operated
- 500 publically available

Of these locations, 459, or 43%, have federal, state or local government ownership/operation. Of those, 111 are available for public access with the remainder closed to the public.

Ownership/operation of the 500 publicly available locations is therefore split 78%/22% between private and government: 389 privately owned and 111 government operated.

The following map shows the geographic distribution of the publicly accessible refueling stations. Immediately evident is the heavy concentration of fueling stations in two geographic areas: California, with 32% of available locations and the South-Central U.S. energy belt (TX, OK, LA and AR), with 19%. These two geographic areas account for just over half of the available publically accessible CNG stations in the country.

The CNG fueling infrastructure is under continuous expansion. Not included in the above figures are the following recent announcements.

- **Trillium/AMP Joint Venture**: Trillium CNG, a business unit of Integrys Energy Group (NYSE: TEG), and AMP Americas announced a joint venture, AMP Trillium, focused on building a network of CNG stations across the US.

Initially, AMP Trillium will construct stations along the I-65 and I-75 trucking corridors and major routes in Texas, with the first station breaking ground by fall 2012. The stations will be open to the public, though the primary customers will likely be heavy-duty and long-haul trucking fleets.

The new stations will feature fast-fill capabilities and redundant equipment providing increased fill speed and reduced downtime backed by a reported 24/7 on-call service-team. To further accentuate the project’s sustainability benefits, AMP Trillium plans to use renewable CNG whenever possible. Renewable CNG is the chemical equivalent of fossil-based natural gas and is obtained from biomass (food or animal waste).
Quasar – Northern Ohio: Six stations are planned to open in Ohio, although timing is uncertain. Quasar will be supplying these stations from anaerobic biomass digesters that produce biogas. The purified biogas, upgraded to natural gas standards, is then supplied to the fueling stations. Quasar has this biomass digester process in place and is already supplying public utilities with their natural gas product.

**LNG Refueling Infrastructure**

The LNG infrastructure is less developed than the CNG vehicle refueling network. As of 7/23/2012, AFDC reports the following:

- 54 LNG Refueling locations
  - 30 Privately Operated
  - 24 Publicly Available

Of the 54 locations, 25 are operated by the Federal Government, with 6 of those accessible to the public. The remaining 18 publicly accessible stations are privately owned. According to AFDC, there are also 98 planned locations announced. The following map shows the geographic distribution of LNG stations in the U.S.

Clean Energy Fuels: This organization already serves over 530 fleet customers and 25,000 vehicles at more than 273 locations across the country. Their customer base includes the refuse, transit, trucking, shuttle, taxi, airport and municipal fleet markets.

Clean Energy has announced construction of a network of fueling stations termed “America’s Natural Gas Highway™”. Partnering with Pilot Flying J, the largest truck stop operator in the U.S., the project is initially planned to comprise approximately 150 LNG truck fueling stations connecting major freight trucking corridors across the country.

The corporation operates two LNG Plants. The first production facility, opened in 2006. It can produce up to 100,000 gallons of vehicle-grade LNG per day and has on-site storage for 800,000 gallons of LNG.

The second facility, opened at the end of 2008, is located in Boron California. Built to produce 160,000 gallons per day, the design allows the plant to be upgraded to a 240,000 gallon daily rate. The site also includes a 1.5 million gallon storage capacity.
Clean Energy is presented here as an example of infrastructure planning and development as of July 2012. ACT will make every attempt to provide an inclusive list as part of the December 2012 update, pending available information.

Clean Energy is planning LNG truck fueling stations at the following locations:

<table>
<thead>
<tr>
<th>Location</th>
<th>Address</th>
</tr>
</thead>
<tbody>
<tr>
<td>Little Rock, AR</td>
<td>1000 E. 21st Street</td>
</tr>
<tr>
<td>Lake Havasu City, AZ</td>
<td>Port Washington, GA</td>
</tr>
<tr>
<td>Coachella, CA</td>
<td>Chicago, IL</td>
</tr>
<tr>
<td>Cotulla, CA</td>
<td>Cuero, KS</td>
</tr>
<tr>
<td>Grand Junction, CO</td>
<td>Hammond, IA</td>
</tr>
<tr>
<td>Hartford, CT</td>
<td>Danville, IL</td>
</tr>
<tr>
<td>St. Augustine, FL</td>
<td>Kaser City Rd</td>
</tr>
<tr>
<td>Yuma, CA</td>
<td>Bridgeton NJ</td>
</tr>
<tr>
<td>Dallas, TX</td>
<td>Fort Worth, TX</td>
</tr>
<tr>
<td>McAllen, TX</td>
<td>McAllen, TX</td>
</tr>
<tr>
<td>New Jersey, NJ</td>
<td>Rockaway, NJ</td>
</tr>
<tr>
<td>Middlebury, IN</td>
<td>Ludington, MI</td>
</tr>
<tr>
<td>North Carolina, NC</td>
<td>Denton, TX</td>
</tr>
<tr>
<td>Suffolk, VA</td>
<td>Hampton, VA</td>
</tr>
</tbody>
</table>

Clean Energy is developing LNG truck fueling stations at the following locations:

<table>
<thead>
<tr>
<th>City</th>
<th>Address</th>
</tr>
</thead>
<tbody>
<tr>
<td>Midway</td>
<td>Callahan Road</td>
</tr>
<tr>
<td>Tifton</td>
<td>Old Linker Road</td>
</tr>
<tr>
<td>DeSoto</td>
<td>Kirksville Road</td>
</tr>
<tr>
<td>Lodi</td>
<td>Old Linker Road</td>
</tr>
<tr>
<td>Waco</td>
<td>Old Jacksonville Road</td>
</tr>
<tr>
<td>Midland</td>
<td>Odessa, TX</td>
</tr>
<tr>
<td>Lubbock</td>
<td>Amarillo, TX</td>
</tr>
<tr>
<td>Lake Havasu</td>
<td>Laredo, TX</td>
</tr>
<tr>
<td>Laredo</td>
<td>Brownsville, TX</td>
</tr>
<tr>
<td>Tucson</td>
<td>Phoenix, AZ</td>
</tr>
<tr>
<td>Medford</td>
<td>Medford, WA</td>
</tr>
<tr>
<td>Springfield</td>
<td>Springfield, MO</td>
</tr>
<tr>
<td>St. Louis</td>
<td>St. Louis, MO</td>
</tr>
<tr>
<td>Seattle</td>
<td>Seattle, WA</td>
</tr>
<tr>
<td>Denver</td>
<td>Denver, CO</td>
</tr>
<tr>
<td>Lakewood</td>
<td>Lakewood, CA</td>
</tr>
<tr>
<td>Las Vegas</td>
<td>Las Vegas, NV</td>
</tr>
<tr>
<td>Las Vegas</td>
<td>Las Vegas, NV</td>
</tr>
<tr>
<td>Midland</td>
<td>Midland, TX</td>
</tr>
<tr>
<td>Lubbock</td>
<td>Lubbock, TX</td>
</tr>
<tr>
<td>Midland</td>
<td>Midland, TX</td>
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<tr>
<td>Lubbock</td>
<td>Lubbock, TX</td>
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<tr>
<td>Midland</td>
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<td>Lubbock</td>
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<td>Midland</td>
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<td>Lubbock</td>
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<td>Midland</td>
<td>Midland, TX</td>
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<tr>
<td>Lubbock</td>
<td>Lubbock, TX</td>
</tr>
<tr>
<td>Midland</td>
<td>Midland, TX</td>
</tr>
</tbody>
</table>
AVAILABILITY OF LNG GLOBALLY

LNG Production and Storage Facilities: It is estimated that by 2020, natural gas will supply about 25% of the global energy demand and with the benefit of being a relatively clean fuel, this percentage will likely increase further. As many of the world gas reserves are geographically isolated from the market, LNT will play a major role in the efficient delivery of energy to the end use.

The production of LNG by conversion of natural gas to liquid is done in a series of processes that are commonly known as “gas trains.” During these processes the gas is cleaned and dried, liquefied by cooling to -260°F and stored in large LNG storage tanks ready for pumping to LNG tankers. (Source: Thermon Group Holdings).

The Energy Information Administration (EIA) reported in 2003 that 55 local utilities owned and operated LNG plants as part of their distribution network. While this information is quite dates, it does provide the perspective of the long-term presence of LNG in the U.S. market, although those early plants were used to meet storage needs of those local utilities rather than creating a product direct end-user sale.

According to the California Energy Commission, there are 26 existing export, or liquefaction marine terminals, worldwide. These facilities are located both on and off shore in 15 different countries. In contrast, there are 60 existing import, or regasification marine terminals, on or off shore, spread across 18 different countries. In addition to these existing terminals, there are approximately 65 liquefaction marine terminal projects and approximately 181 regasification terminal projects that have been either proposed or are under construction around the world.

Countries that Export LNG
(Start-up date of earliest liquefaction terminal in parentheses)
- Algeria, Republic of (1971)
- Australia, Commonwealth of (1989)
- Brunei, State of (1972)
- Equatorial Guinea, Republic of (2007)
- Indonesia, Republic of (1977)
- Libya (1970)
- Malaysia (1983)
- Norway, Kingdom of (2007)
- Oman, Sultanate of (2000)
- Qatar, State of (1997)
- Trinidad and Tobago, Republic of (1999)
- United Arab Emirates (1977)
- United States of America (1969)

Countries that Import LNG
(Start-up date of earliest regasification terminals in parentheses)
- Belgium, Kingdom of (1987)
- Dominican Republic (2003)
- France (1972)
- Greece (2000)
- India, Republic of (2004)
- Italy (1971)
- Japan (1969)
- Mexico (2006)
- Portugal (2003)
- South Korea, Republic of (1986)
- Spain, Kingdom of (1969)
- Taiwan (Republic of China) (1990)
- Turkey, Republic of (1992)
- United Kingdom (2005)
- United States of America (1971)
CLASS 8 NATURAL GAS VEHICLE FORECAST THROUGH 2030

The natural gas project to this point was designed to determine if natural gas is a viable long term candidate to replace diesel in a substantial portion of Class 8 vehicles. Our analysis of the content thus far presented convinces us the answer is yes. Natural gas is and will be available, it has a cost advantage compared with diesel, and products and infrastructure needed for adoption are being put in place. There is, however, much that is still to be done. Truckers and the nation need the cost savings of natural gas while we move to a more environmentally friendly transportation system, the system that is the backbone of our economy in a highly competitive global environment.

Building on ACT’s expertise in forecasting the Class 8 truck market, combined with the understanding of potential for natural gas developed during this project, we have develop a forecast of the share of Class 8 natural gas vehicles through 2030. The total natural gas unit forecast is based on this share projections and the U.S. Class 8 Retail Sales forecasts through 2017 found in ACT’s NA Commercial Vehicle Outlook and through 2022 in the GCVF (Global Commercial Vehicle Forecast).

Scope: The natural gas Class 8 forecast is based on our projected shares of U.S. retail sales of all Class 8 vehicles. These correspond to the Class 8 vehicles we forecast in table 14 of ACT’s NA Commercial Vehicle Outlook and the GCVF. This study provides share projections for the following segments and sub-segments: Truck Load, Less than Truckload, Expedited, Owner Operator, Private Fleets, Refuse, Municipal, and Other. In addition to these segments, we have added a forecast of Transit Buses which are not covered in either publication.
Summary: Natural gas (NG) will take its place with gasoline and diesel as the U.S.'s third motor vehicle fuel, with about 1/3 of U.S. Class 8 vehicles powered by NG in 2020, increasing to about 50% NG penetration 5 years later. As this report is being written, we are in a period where the necessary preconditions are being put in place to escape a ‘chicken and the egg’ dilemma: Which comes first, NG vehicles or NG fueling stations? We are approaching point where for many truckers the cost benefit analysis tips in favor of natural gas and adoption will take off. A classic “S-curve” of new technology adoption is anticipated (see page 126). Detailed NG share by Class 8 sub-segment are on page 139.
ASSUMPTIONS

Major Assumptions:

1. Environmental concerns will not be a roadblock to adoption.
2. The cost of diesel will be sufficiently above NG to provide a reasonable rate of return on the total investment (new truck price, facilities, financing, training, etc.) to switch to NG.
3. The NG wellhead price will be sufficiently high to insure continued production. This was discussed in Chapter 1, “Natural Gas and the U.S. Energy Market.”
4. The fueling infrastructure will be sufficient, particularly for long haul truckers. This was discussed earlier in this chapter under the heading “Natural Gas Refueling Infrastructure”, which begins on page 122.

Assumptions 1 and 2 are discussed below:

Assumption #1: Environmental concerns will not be a roadblock to adoption.

The basic debate, at least over our forecast horizon, is whether to fuel Class 8 vehicles with NG vs. Diesel. At this point the question is not whether to fuel Class 8 vehicles with fossil fuels (NG and diesel) vs. other alternatives. Moreover, the question is certainly not whether a fundamental reduction in reliance on Class 8 vehicles is an option. Within the forecast horizon of this paper, the elimination of Class 8 vehicles and diesel power is a virtual impossibility. This is because there is no alternative transportation mode to move freight from between many geographically dispersed locations in a timely manner. (There has been a great deal of discussion and analysis of shifting from trucks to intermodal, the core of which is rail. Even if intermodal had a 100% increase, this would have a relatively small impact on trucking. In addition, trucks are used to take goods to and from intermodal railheads. The truck length of haul is often less than the economical haul for intermodal. Finally it must be remembered that nearly 30% of Class 8 vehicles are used in the vocational market which is completely local so there is no alternative.)

While natural gas combustion produces less CO₂ than diesel, serious concerns have been raised about the extraction and pre-combustion handling of NG, in part because methane has higher radiative forcing than carbon dioxide. As environmental science is not an area of ACT’s expertise, we decided early in the project to focus on the economic/industry factors directly impacting the adoption of natural gas as a fuel of choice rather than trying to reach conclusion on the scientific context and public policy direction.

An essential precondition to the takeoff of NG as a replacement for diesel has been the tremendous increase in NG supply—and consequent price drop, due to horizontal drilling using hydraulic fracturing or frac’ing. Concerns regarding this method include those related to fracturing rock formations with a water/chemical/sand mix (water table contamination and earthquakes) and surface contamination due to recovery of the mix. These may be primarily local/regional concerns. Escape of methane from the wellhead into the atmosphere is a global concern. Escaped methane is also a concern for NG transportation, processing, vehicle fueling, and storage (in processing plants, fueling stations, and on vehicle).

We have assumed that these concerns will NOT be a roadblock to adoption for one or more of the following POSSIBLE reasons:

- A consensus will be reached that lifecycle environmental impacts of NG (from geological formation to combustion to the atmosphere) are no more harmful than those of the diesel it replaces (much of which is refined from oil that is transported across oceans), and thus no action need be taken.
- If NG is environmentally worse on balance than diesel (or if society determines NG environmental concerns must be addressed), engineering countermeasures will be developed and adopted that reduce NG’s harmful impacts to ‘acceptable’ levels without fundamentally altering the path of adoption of NG as a Class 8 fuel.
- For most Class 8 sub-segments, the decision to move from diesel to NG will take place largely without reference to environmental costs or benefits. Rather, economic and perhaps geopolitical factors will dominate.

The fact that environmental factors have not fundamentally impacted the amount of frac'ing in the U.S. adds weight to the above perspective.
Assumption #2: NG will produce a reasonable rate of return for truckers.

There are numerous financial and non-financial elements to a decision regarding shifting from diesel to NG, including the following:

- Total fuel related savings for NG
  - Fuel
    - Price at the pump for NG and diesel
    - Mileage
  - DEF and particulate filter costs
  - Maintenance differential
- Upcharge for natural gas vehicles
- Miles driven per year

The above items are captured by the "First Step Simple Savings" NG Vehicle Payback Calculator, which is provided to subscribers to this study and is described on page 130.

Other elements in a well analyzed rate of return include the following:

- Interest payments on the upcharge
- Cost of capital to finance the upcharge
- Tax considerations/depreciation/cash flow
- Increased insurance on more expensive vehicles (and possibly the technology)
- Cost of bringing repair facilities up to fire codes for natural gas
- Costs of handling of cryogenic LNG
- Training, not only of drivers and technicians but also of accounting, sales, marketing, trainers, HR and other staff
- Payload reductions to offset NG vehicle weight increases over corresponding diesel vehicle
- Time to fueling (which reduces time available for driving under into Hours of Service [HOS] rules)
- Residual value at first trade in/end of lease
- Supplemental compensation

Additional strategy factors include the following:

- Fueling station availability
- Customers negotiating away some savings,
- Sustainability commitment
- Social cost/benefit of natural gas vs. diesel
- Green marketing
SIMPLE PAYBACK CALCULATOR

Simple Payback: To help subscribers to this study understand factors impacting the decision as to whether it makes sense to shift to NG, we have developed a “First Step, Simple Savings” Natural Gas Vehicle Payback Calculator. It is one of two tools in the “NG Calculators” Excel workbook which was distributed with the electronic copy of your report.

**INPUTS**

<table>
<thead>
<tr>
<th>YOUR OPERATION</th>
<th>A Miles per Year</th>
<th>100,000</th>
</tr>
</thead>
<tbody>
<tr>
<td>B Trade Cycle (years)</td>
<td>5</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ENERGY RELATED</th>
<th>Natural Gas</th>
<th>Diesel</th>
<th>(Worse) Diesel</th>
</tr>
</thead>
<tbody>
<tr>
<td>C Price at Pump *</td>
<td>$2.50</td>
<td>$4.00</td>
<td>1.50</td>
</tr>
<tr>
<td>D Engine Efficiency % of Diesel*</td>
<td>90%</td>
<td>100%</td>
<td>-10%</td>
</tr>
<tr>
<td>E MPG (Miles per DGE for NG)</td>
<td>6.075</td>
<td>6.75</td>
<td>(0.68)</td>
</tr>
<tr>
<td>F Price of Diesel Exhaust Fluid</td>
<td>n/a</td>
<td>$2.40</td>
<td></td>
</tr>
<tr>
<td>G Percent DEF Usage</td>
<td>n/a</td>
<td>2.50%</td>
<td></td>
</tr>
<tr>
<td>H Particulate Filter (Annual)</td>
<td>n/a</td>
<td>$275</td>
<td></td>
</tr>
<tr>
<td>I Annual Maintenance</td>
<td>$3,001</td>
<td>$3,000</td>
<td>$ (1)</td>
</tr>
<tr>
<td>J Other Annual (e.g., tax rebates)</td>
<td>$ -</td>
<td>$ -</td>
<td>$ -</td>
</tr>
<tr>
<td>K Sticker Upcharge for Natural Gas</td>
<td>$30,000</td>
<td>0</td>
<td>$ (30,000)</td>
</tr>
<tr>
<td>L One Time Subsidy</td>
<td>$ -</td>
<td>$ -</td>
<td>$ -</td>
</tr>
<tr>
<td>M Net Upcharge (Initial Investment)</td>
<td>$30,000</td>
<td>0</td>
<td>$ (30,000)</td>
</tr>
</tbody>
</table>
The inputs include the following assumptions:

- NG costs $2.50 per DGE at the pump
- Diesel is $4.00 per gallon at the pump
- The diesel vehicle achieves an average of 6.75 mpg
- The NG engine is 90% as efficient as the diesel engine resulting in 6.075 mpg
- The vehicle is driven 100,000 per year
- The upcharge for a NG vehicle is $30,000

In this example, the SIMPLE PAYBACK results can be seen below:

One must drive 155,667 miles under the assumptions to save enough in Total Fuel Related costs to pay for the $30K upcharge (again excluding a number of financial details). This results in a simple payback of 1 year and 7 months (at 100,000 miles per year) i.e. upcharge/annual fuel related savings = $30,000/$19,272 per year = 1.6 years. The calculator shows the trucker in this example would have to burn 25,624 DGE to offset the $30,000 upcharge.
To help the trucker or calculator user visualize the interplay of fuel price differential and equipment upcharge, two graphs have been developed. In the graph, below we plotted miles to diesel fuel cost for three upcharge scenarios: $30K, $50K, and $75K.

In each case it is assumed a DGE costs $2.50 at the pump. Other assumptions listed in the chart’s title block. The calculated result for the assumption shows that 156k miles need to be driven when diesel costs $4.00/gal to achieve a simple payback for the $30k upcharge for the NG vehicle.
The graph below takes the information used to construct the previous graph and converts it to the number of gallons of diesel (left axis) and the corresponding DGEs (right axis) one would have to burn for the savings to pay for the upcharges in the 3 equipment cost scenarios. Again we assume diesel achieves 6.75 mpg and NG, with 90% engine efficiency, achieves 6.076 miles per DGE.

The gap between the diesel and NG price paid by truckers is key to the decision to adopt NG. ACT’s forecast assumes the gap between the cost of NG at the pump and diesel will be sufficient to produce an adequate return.

The graph on page 134, “Trend of Natural Gas Compared with Diesel” supports this assumption. In this graph, the EIA’s forecast of spot prices for natural gas (the green dotted line) closely tracks diesel (the red line with squares) through 2030 which is ACT’s forecast horizon in this study. However, the price of natural gas traded on commodity markets is not the primary driver of NG at the pump. This is a fundamental distinction between diesel and NG: The primary driver of diesel price is the global cost of a barrel of oil. The primary driver of NG is the price truckers are charged for transportation, processing, and storage, plus profits added by firms supplying NG to truckers, all domestically based. Thus, the solid green line with triangles has been added to provide an estimate of the price at the pump for natural gas. This line is relatively flat, rising only of 15% from 2012 to 2030 while NG at the Henry Hub rises 76%. (The Henry Hub most important NG pipeline hub point and the most quoted market price.) By comparison, diesel increases 58% during this period. Thus, to people who say “What about if the price of NG goes back up?” the answer is that only a small part of the commodity price is included in the DGE.

To stress the potential path of the difference between the price of diesel and NG at the pump, a thick purple line has been added to the chart. It has been negative, but, if the EIA projections are accurate and ACT’s model is reasonable, NG will have $1.50/ gallon advantage over diesel in 2015 and a $2.00 advantage by 2020. However, the
purple line may understate the difference (Actually, this line understates the NG advantage because the EIA diesel prices has only state and federal taxes while ACT’s “NG Price at the Pump” calculator has a national estimate of state, federal, and local taxes). If diesel prices increase at a faster rate, NG’s advantage is definitely understated. Conversely, it is possible that the increase in supply of NG may depress other energy prices, including oil and thus diesel. In any event, we think that this differential will not fall below $2.00 after 2020, as indicated by the thin purple line. A $2.00 advantage for NG will be advantageous for many truck purchasers, especially as the price of NG components and systems fall as NG equipment volumes increase.

Note: The ACT Diesel (compression) and Natural Gas (spark) Calculators can be found at http://calc.actresearch.net/. They are available for testing after sign in. A Dual Fuel (compression) Calculator will be available in December 2012.
PRICE AT THE PUMP CALCULATOR

The prices at the pump for NG were calculated using the second tool in the “NG Calculators” Excel workbook, the “Diesel Gallon Equivalent Price at Pump Calculator.” A screen shot of this calculator is presented below. A primary use of this tool is to demonstrate to those who worry about the commodity price of NG increasing that the impact on the trucker is a fraction of the change of the commodity price. For example, the calculator shows that if the Henry Hub Price of $3.22 per million BTU or MMBtu (July 31, 2012’s actual) is doubled, the result is only an 18% increase in the price per DGE at the pump. The calculator currently assumes that each DGE has $1.50 of transportation, processing, storage and profit in it. The calculator includes taxes (at the U.S. average for federal, state and local). All of these inputs can be changed by you to develop alternative scenarios. In addition, there are optional inputs for additional markup and other charges/reductions (for example, tax rebates).

Note: The ACT DGE Price at the Pump Calculator is available for testing Go to http://calc.actresearch.net/.
ACT’S FORECAST: STAGES OF ADOPTION AND A BOTTOM UP APPROACH

Stages of Adoption:

In thinking about ACT’s forecast, it is useful to use a framework inspired by W.W. Rostow’s Stages of Economic Growth. These stages are indicated on in the graph on pages 126 and 139.

- **TRADITIONAL STAGE**: Diesel is the Class 8 fuel of preference from the mid-70s to around 2010
- **PRECONDITIONS FOR TAKEOFF**: From about 2011 through 2013
- **TAKEOFF OF ADOPTION**: From about 2014 through 2022
- **DRIVE TO MATURITY AND STEADY STATE**: From about 2023 on

While there may be no ‘bright line’ between the stages, they provide a useful narrative and conceptual framework to understand how a transition to increased NG usage can occur.

During the Traditional Stage, from the mid-70s, diesel is the preferred fuel for Class 8 trucks. However, during 1999-2005 there was a period when vocal minorities promoted NG for internal combustion engines, particularly automobiles. In addition, niche markets developed where environmental considerations dominated. In some cases purchases were subsidized by the government. These included refuse trucks, buses, and ports. In general, however, the widespread adoption of NG in Class 8 did not receive widespread consideration; the driving and restraining forces in the “Force Field Analysis” (page 108) were not a play.

Over the past few years frac’ing has increased the supply of NG substantially. The mild winter of 2011-12 resulted in a drastic drop in NG spot prices as the limits of NG storage were reached. These pressures resulted in a dramatic decrease in NG exploration. These events, together with major marketing efforts by several engine and truck manufacturers, focused the attention of the industry on this fuel. Thus, we date the beginning of the Stage of Preconditions for Take Off at 2011. Today niche markets are well established. Beyond the niches, fleets are conducting detailed evaluations of NG vehicles. Numerous product offerings and plans were presented at the March 2012 Mid-America Trucking Show. There is a thirst for basic understanding of how NG might work as leaders of the industry attend seminars and purchase reports. Great progress is made resolving the driving and restraining forces. More (and more powerful) NG engines and vehicles are becoming available. Huge investments are made in the fueling infrastructure. This stage began with comments like “which comes first, the chicken or the egg”, the product on the road or the fueling station and other infrastructure. By the end of the stage a critical mass of engines, trucks, and infrastructure will begin to propel NG adoption and there will be a way forward to address environmental concerns.

Next is the Takeoff Stage. In this stage there will be enough product and infrastructure to give buyers of new trucks a true choice. The forces for and against change will have been largely resolved. In depth financial calculations and strategic analysis will be developed. In addition, the gap between NG and diesel pump prices will become more favorable to NG. Major fleets will see the “handwriting on the wall” and develop strategies to incorporate NG into their operations. This may result in purchasing of vehicles with a slightly longer payback to better understand the details needed to insure this technology is integrated seamlessly. Nothing succeeds like success, and as some truckers reap financial rewards from NG adoption, others will be forced to do so defensively; there is no other way to take major costs out, at least in the short and medium terms (the “low hanging fruit” of relatively inexpensive technologies that improve fuel economy have been adopted). Economies of scale will begin to appear and more suppliers will see market opportunity and develop less expensive components, further improving the return on the NG investment. Firms which produce ‘diesel only’ components will begin to see market share erosion and possibly share price declines.

The start of the takeoff is hard to time. Unexpected strength of restraining forces can delay the takeoff, pushing the steep section of the S-curve to the right. Geopolitical events could shift it unexpectedly to the left.

The stages end with a Drive to Maturity and NG Steady State Share. The number of engine and...
vehicle offerings will be on a par with diesel. Cost and benefits for various vehicle usages and duty cycles will be well understood. People will find it hard to imagine a time when NG was not a major Class 8 fuel, just as people today cannot imagine trucking without diesel.

A Bottom Up Approach: The adoption of successful technologies generally follows an S-shaped curve. While we began our forecasting with this in mind, we did not apply it in a top-down manner; each sub-segment within the Class 8 market has different usages and different duty cycles. (The Class 8 segments are For Hire, Private Fleets, Vocational, and Transit Bus.) Thus we made an estimate for each major sub-segment; our total U.S. Class 8 retail sales forecast is an average of the sub-segment forecasts, weighted proportion of the market held by that sub-segment.

An outline of our sub-segment by sub-segment forecast is as follows:

- We forecast that by as early as 2020 refuse truck will be 95% natural gas, the highest share of any sub-segment. This is because this sub-segment has all of the factors that encourage adoption:
  - ‘Return home’ at night which provides an opportunity for slow refueling
  - Firms and municipalities operating refuse trucks often have a commitment to sustainability: reduce, reuse, and recycle.
  - Refuse trucks are highly visible, and are operating by firms or municipalities that employ green marketing
  - Some refuse companies can convert methane which comes off of landfills into fuel
  - A substantial proportion of refuse trucks purchased today are NG. They are well integrated into their operation.
  - Very long trade refuse truck trade cycles allow for payback.
- The Transit/Municipal buses segment shares many of the refuse truck reasons for adopting NG. While we believe most transit buses will move away from traditional diesel, NG will share the market with other energy sources and hybrid technologies.
- We anticipate that private fleets will lead for hire over the road fleets in both speed and quantity of adoption. One reason is that their trucks often return home at night allowing for slow fill refueling. Private fleets tend to be able to innovate quicker because truck transportation is a means to do their business rather than being their business. They often have a strong sustainability commitment and/or engage in green marketing. Truck operations are generally a relatively small part of their financial performance. Thus decision regarding truck purchases can be made on more of a long term basis without quarterly scrutiny of the investment community.
- Many expediters/delivery firms are household names; they are motivated by their sustainability commitment and green marketing in addition to simple financials. We anticipate their adoption profile to be similar to municipalities.
- Truck Load (TL) carriers will adopt NG initially along routes which have substantial numbers of fueling stations. Larger operators will install NG facilities at their terminals. Vehicles which are dedicated to cargos that weigh out (about 1/3), are extremely time sensitive, or have the highest shipping rate per pound will be the least favorable candidates for NG. It is possible that fleet management software will help allocate NG vs. diesel vehicles.
- Less than Truckload (LTL), if they operate under present strategies (night time line haul, day time delivery), will lag TL carriers both speed and quantity of adoption due to LTL duty cycles. Although LTL vehicles spend several hours each night in a hub-and-spoke terminal, this time may not be sufficient for slow refueling.
- Because of the applications, duty cycles, and the fact the construction industry has many small participants, this sub-segment will be a relatively low adoption rate. An exception will be the dump truck sub-segment. Many dump trucks sit idle through the night at “home,” allowing for slow refueling.
- **Owner operators**, who buy relatively few new trucks, will be the group with the lowest NG adoption rate. This is in large part due to up front upcharge and fear of low residuals. To some degree, it may be due to owner operators’ negative perceptions of NG. Those who have long term contracts with major shippers who help them purchase/lease new trucks will be a major portion of owner operators who purchase NG.

- **Other uses** (wreckers, etc.) will have a low adoption rates because their duty cycles are not conducive to NG fueling.

The next page contains ACT’s complete NG baseline forecast through 2030:

- A graph presenting NG’s overall Class 8 share over the 4 stages of adoption, and
- A table with each Class 8 sub-segment’s share and the total number of NG Class 8 trucks and buses

In addition to providing readers of this study with a starting point for considering NG adoption, a purpose of this forecast is to promote debate and comment, discussion in which we invite you to participate at our seminars and/or by phone call. In addition, this baseline forecast will be the basis and comparator for all future NG forecasts, if any are developed, either in response to comments from subscribers to this study or as part of project work for our consulting clients.
# ACT’s Forecast: Graph and Detail by Sub-Segment

## Stages* of U.S. Class 8 Natural Gas Adoption--Baseline Scenario

(Class 8 Truck Retail Sales Plus Transit Buses)

![Graph showing stages of U.S. Class 8 Natural Gas Adoption](image)

### U.S. Class 8 Natural Gas Adoption Rates--Baseline Scenario

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### NG Share of Class 8 Truck and Bus Sales

<table>
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<th>SALES OF NG TRUCKS AND BUSES (000)</th>
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**Memo:**

- Total NG Vehicles 2009-12: 4, 7, 8, 12

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CUMULATIVE RETAIL SALES FORECAST

The graph below displays the number of Class 8 NG retail sales we forecast from 2013 to 2030 (dashed line), the cumulative retail sales (red line with squares), and the cumulative vehicles that remain in the population (green line with triangles). The difference between cumulative sales and the slightly lower line is vehicles which have left the population due to scrappage. An example of scrappage would be a vehicle destroyed in a flood.

![U.S. Class 8 Natural Gas (NG) Retail Sales Projection 2013-2030](image-url)
RISKS AND OPPORTUNITIES

As with any forecast, particularly one that goes out 18 years into the future, there are many “known unknowns” and “unknown unknowns” which will influence NG’s actual adoption.

In the short and medium term (to 2020) there are more risks that NG “takeoff” will be delayed or develop more slowly than our baseline that that it will occur at a faster pace. In other words, it is more likely that the S-curve will shift to the right rather than to the left. On the other hand, after 2022 when our baseline scenario enters the “drive to maturity and steady state share,” it is possible that the “takeoff” will continue, resulting in higher adoption long term adoption rates. The justification for these reasons is presented below:

Short to Medium Run (to about 2020)

Note: Some of these events might also occur in the Medium to Long Run

- By far the greatest short term risk is that the fueling infrastructure takes materially longer to put in place than anticipated.
- A second risk in terms of high probability and impact is that total Class 8 sales will be lower than ACT’s forecasts. While a simple reduction in the number of trucks would result from this reduction without changing the NG share, we believe a poor economy which would drive total sales down would also negatively impact the NG share because a) an upcharge is harder to justify in a poor economy, and b) risk aversion increases in times of economic, uncertainty, and adopting NG is still perceived as a risky compared with purchasing diesel which is a known quantity.
- On the positive side it is possible that government subsidies, either in lower DGE tax rates, tax credits for the upcharge, or direct subsidies for purchase might be adopted to encourage a “greener” Class 8 fleet. While there may be some state programs, we believe it is unlikely that new federal programs that might add to the deficit will be enacted whichever party controls Congress and/or the White House.
- A regulatory change which would not increase the deficit would be to allow NG vehicles to carry heavier payloads by an amount representing the approximate increase in weight for NG vs. diesel. For example, is an NG vehicle is 1,200 pounds heavier than its diesel counterpart, the NG vehicle would be allowed a total weight of 81,200 pounds compared to the diesel's 80,000.
- OEMs charge less for NG vehicles than anticipated to buy market share or promote quicker adoption (allowing them to move up the economies of scale curve).
- Cost reductions for NG components, engines, and vehicles are faster (or slower) than anticipated.
- If the firms which sell NG in the Class 8 market raise the price of DGEs closer to diesel, they might erode the NG advantage to such an extent that adoption is discouraged.
- Negative stories about operational difficulties become widely discussed, e.g., a California school district that has parked its NG buses because it does not have funds for mandated inspections.
- Regulations are enacted on the drilling, and/or transportation and/or storage of NG that materially add costs that make it less attractive.
- Drastic non-trend price changes of oil or NG:
  - A collapse in NG prices that would make exploration, drilling, and extraction uneconomical, drying up the supply.
  - A collapse in oil prices that would make diesel more attractive.
  - An increase in oil prices due to worldwide economic recovery (e.g., China) that would make NG more attractive.
  - NG supply increases exert substantial downward pressure on oil, reducing the relative attractiveness of NG.
  - A geopolitical crisis drastically reduces the supply of oil to the U.S., which could increase the incentive to more to NG.
Medium to Long Run

- Oil prices might rise more than the EIA projections if the developing world has higher per capita petrochemical usage than forecast, making NG more attractive.

- New (possibly foreign) entrants into the NG component/engine/vehicle market drive down prices, making NG more attractive.

- The world experiences another major financial recession on the scale of that in 2008-9. This would severely dampen truck demand, particularly new, more expensive technologies.

- Changes in regulations could favor either NG (restrictions on CO₂ emissions) or diesel (restrictions on methane emissions).

- Climatic change and environmental science might reach a point where world leaders develop binding treaties which in turn have a major regulatory impact. These might:
  - Fundamentally alter the cost/benefit calculation between diesel and NG.
  - Add costs to NG extraction, transportation, and storage.
  - Promote technological change.
  - Reduce shipping by truck, trading off present economic prosperity for future environmental benefits.

- A technological innovation changes the NG vs. diesel cost benefit calculation.

Invitation

ACT’s forecast is based upon research into the field, detailed discussions with industry experts, a panel and e-mailed questionnaires, and our knowledge of the industry. It will serve as a basis for further analysis forecasts and we hope energetic discussions within and among our client companies. We look forward to your comments.
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Chapter 8: DISCUSSION OF INDUSTRY QUESTIONS

The Baker's Dozen (13 Common Misconceptions) ........................................... 144-146
Panelist’s Questions .................................................................................. 147-150
Answers to Unasked Questions ................................................................ 151-152
THE BAKER’S DOZEN
(13 COMMON MISCONCEPTIONS)

Throughout the course of the project, we have come across questions about natural gas that show a wide knowledge gap on the topic. The following are the thirteen most frequent misconceptions we encountered and our redress to those misunderstandings.

1) **Natural gas powered tractors are too heavy.**
   Two thirds of trailers “cube out” before they are “gross out”. For tractor trailers hauling grossed out (maximum weight), natural gas powered trucks might not be the answer. For two thirds of the vehicles used, natural gas powered trucks might offer a lower cost alternative on a cost per loaded mile basis. Load hauling capacity is measured in horsepower and torque. A unit of horsepower or torque is the same for any engine, regardless of the fuel that powers it. For a given cubic inch of displacement though, a natural gas fueled engine will produce less horsepower and torque than the same displacement diesel. Currently, the heavy duty natural gas engines that are available have a maximum rating of 475 HP and 1,750 ft. pounds of torque and are 15 liters in size. However, numerous companies have announced the development of natural gas powered engines of less than 15 liters of displacement with horsepower and torque ratings that will allow them to pull fully loaded Class 8 trucks in virtually any environment and offer overall performance similar to a diesel. The engine performance will be there. Then, the question will become which category of load prevails, grossed out or cubed out. For two thirds of the market that are cubed out, natural gas fueled engine may offer a lower cost per loaded mile alternative.

2) **Natural gas engines do not have a long enough range of operation.**
   The last thing any trucker wants to do is run out of fuel while on the road. Finding that a distant station is for cars only doesn’t solve the problem. Range of operation, or distance between fueling stops, is a function of the amount of fuel carried on the truck and the efficiency at which the engine operates. Admittedly, natural gas is not as efficient as diesel fuel. The term operator’s use is “range anxiety”. Therefore, as with many specifications, trade-offs might be necessary to achieve the desired range of operation. Additional fuel tanks can extend range, but also add weight. More frequent refueling stops are another possibility, but reduce overall efficiency. Properly spec’ing the vehicle to the work to be done is the best solution to this concern. There are many new natural gas fueling stations under construction, announced, planned, or under consideration. Until such time as operators and potential natural gas operators see all this as bricks and mortar and an actual place to refuel a tractor trailer combination with natural gas, range anxiety will prevail. Today, range anxiety leads people to consider LNG as the answer but they realize that they pay a premium for the LNG over CNG. With more fueling station availability, operators will be able to sort the CNG or LNG preference.

3) **There are not very many natural gas powered trucks available.**
   This is a fair observation, but also a situation that is very dynamic. One needs to keep in mind that this is a segment that is still in its infancy. It is only in the last few years that natural gas has become a financially viable alternative to diesel and it will take some time to build the product offerings. Currently, every North American heavy truck OEM except Western Star offers at least one natural gas powered truck. As more powerful engines become available (2013), the type and variety of trucks will also expand. In 2013 and 2014, operators will have multiple choices of whether to use CNG or LNG fuel and whether they prefer LNG pilot injection engine options.

4) **Natural gas engines are less fuel efficient, so they don’t end up saving money.**
   Natural gas engines are less efficient but the fuel used costs much less than diesel. Thus, a natural gas fueled engine can operate at a lower cost per mile. As we already established, diesel fuel is the most efficient fuel available. However, the cost differential between diesel and natural gas is where the real savings is. Refer to the table on the bottom of page 75 for several examples of the savings that are possible from switching to natural gas. The payback calculator will provide similar analysis that allows adjustments to the estimates on the above referenced example.
5) **Natural gas powered vehicles cannot provide a sufficient return on investment without government assistance.** Whether the particulars of a given transaction meet given ROI hurdles depends on many factors. Once again, the payback calculator is a tool that can be used to perform such analysis. In the examples we present, a very reasonable payback is possible without the use of government assistance. Also keep in mind that may adopters of new technology do so for reasons that cannot be quantified in an ROI analysis. Incentive money was used to get cleaner natural gas engines into operation. It was all part of the “Going Green” movement. Operators are not being forced to use natural gas fueled engines as both natural gas and diesel engines can meet the stringent 2010 emission standards. ROI calculations allow each individual to decide his or her best choice in fuel selection.

6) **Maintenance costs for natural gas engines are too high.** Roughly 80% of the contents of diesel and natural gas engines are common and most of the maintenance needs are very similar. For a given displacement size engine, the maintenance schedules are nearly identical. Many times, this concern comes from comparing underspec’d natural gas engines against higher horsepower and larger displacement diesel engines. When larger displacement spark ignited engines with more horsepower and torque become available in 2013, more enlightening cost comparisons can be made, including servicing the diesel DPF (Diesel Particulate Filter) and the added cost of DEF (Diesel Exhaust Fluid). With the new and soon to be released spark ignited natural gas engines, we should see longer oil drain and spark plug change intervals. This should help equalize maintenance cost comparisons.

7) **Drivers won’t like natural gas engines.** This statement is true when they are asked to drive natural gas fueled trucks that have less horsepower, torque, and overall performance than diesels they previously drove. This is especially true with spark ignited natural gas engines. Drivers want performance because the vast majority of them are not paying for the fuel. However, with proper training and communication, drivers can come to appreciate the cost savings and environmental contribution natural gas engines make and will accept them. Another benefit is that NG engines run quieter than diesel engines, which the drivers are sure to appreciate.

8) **Shop modification is too costly.** This is probably the most frequently misunderstood of all perceptions regarding natural gas vehicles. While it is true that certain precautions must be taken to ensure the safe servicing of natural gas powered vehicles, it is not necessary to convert the entire service facility, at least not initially. The amount of conversion should be proportional to the penetration of NG powered vehicles in the fleet. Initially, repairs can even be made outside the shop facility to delay any capital investment. Any new shop construction should be done with natural gas safety regulations in mind as conversion costs are always higher than initial construction costs.

9) **Pro-environmental (anti-frac’ing) groups will be successful in getting drilling operations shut down, resulting in a severely curtailed supply of and significantly higher prices for natural gas.** Clearly, opposition groups have been much more vocal than proponents, or at least they get more coverage in the popular press. Concerns about increased earthquake activity, contaminated groundwater, and inadvertent venting of GHGs make for sensational news stories. Further, they deserve to be studied and understood, and then a judgment be made as to how best to proceed. As a stakeholder in the natural gas market, this is a good time to get involved and make one’s voice heard and one’s vote count. Sadly, our nation has no comprehensive, long-term energy policy. While there are numerous federal provisions and an even more prolific number of state-specific programs, none of them work together cohesively to adequately address important topics such as energy security, conservation (reduction), subsidies, etc.

10) **The fueling infrastructure permitting and construction process is too slow and will not keep pace with truck purchases.** This concern deals with both construction of on-site refueling and service facilities. Dealing with regulatory entities can be challenging, but with
proper understanding of applicable regulations and a little advance planning, there is no reason for brick and mortar to delay scheduled truck delivery. Retention of a consultant specializing in such endeavors is another means to ensure harmony. This doubt has also been expressed as it relates to commercial refueling stations. Numerous natural gas providers have announced station construction plans that are progressing well. For example, Clean Energy completed 68 new stations in 2011. They are on pace to complete 70 more stations in 2012 as part of their plan to add 150 new facilities by the end of 2013. Interestingly, there have been some reports of LNG stations that have been completed and are waiting for a sufficient concentration of trucks before they begin selling fuel.

11) Natural gas is not safe. Of all the objections against natural gas, this is the most emotionally charged. Natural gas in transportation has been proven safe. We need to remember that over 70 million households and businesses in the U.S. alone use natural gas to heat their homes, cook their food, and dry their clothes every day. As with any potentially flammable substance, proper care must be exercised when handling it, but it is just as safe, if not more so, than gasoline and diesel. Because it is a gas, rather than a solid, it will vent up into the atmosphere in the event of a leak, rather than pooling like a liquid. In addition, the combustion point, or the temperature at which it will ignite, is roughly twice as high as that of gasoline and diesel. According to a recent survey by the American Gas Association, there have been no injuries or deaths related to the use of natural gas in vehicles.

12) Customers do not care about sustainability. This is another facet that was not directly addressed in this study, but nearly every stakeholder in the industry counts sustainability among the reasons they are interested in natural gas as an on-highway fuel. In short, the “Going Green” movement is alive and well in North America.

13) Natural gas is just not for me. Despite all the facts and benefits we have provided in the paper, some will still contend that there is no sufficient benefit for them to switch to natural gas. In all honesty, that may be true. Natural gas is not a panacea. There are surely circumstances where NG will not pay. Even diesel, with its superior efficiency, has yet to capture 100% of the U.S. Class 8 on highway market. However, we believe all truck buyers owe it to themselves to at least go through the analysis and answer the question, “Is natural gas the diesel of tomorrow?” If early adopters are successful and are rewarded with lower costs and increased profits, others will need to take a closer look.
PANELIST’S QUESTIONS

In addition to the questions we asked panelist that are summarized in Chapter 6, we also asked them if there was anything about natural gas as a fuel for heavy duty vehicles that they would like to have addressed in this project? Below are the responses to those questions, along with our responses, where applicable.

TANK INFORMATION

- Is there a definitive answer to the question of how much CNG tanks weigh and what their range capability is? Definitive might be too strong a choice of word, but there are definitely known answers to the question. The problem lies in the number of variables that are encompassed. There are currently four types of tanks defined by their construction and materials. Type 1 tanks are constructed entirely of steel and are the heaviest. Type 4 tanks make use of lighter weight materials. Each type is priced according to its base material and also has its pros and cons in terms of capacity, etc. In addition to type, tanks also come in different sizes, and therefore vary in weight. The number of tanks, and hence the operating range of the vehicle, also play a role in determining incremental weight. As was previously discussed, range capability is a factor of the amount of fuel carried on board and the fuel efficiency of the vehicle. The best answer to this question will come from working with a natural gas vehicle manufacturer to determine the best spec and configuration for a potential buyers’ particular intended use.

LONG TERM PRICE OF NG

- Will the long-term price of NG stay low or will the decrease in frac’ing raise the price? Invariably, the cost of natural gas will fluctuate, as will the cost of diesel. The more important factor on which to focus is the relationship between the two and the drivers of the cost differential. Thanks to the abundant supply of natural gas, its cost is much lower than that of crude oil, the primary raw ingredient of diesel fuel. Given the current pricing, natural gas prices would have to more than quadruple before they would begin to approach today’s diesel prices.

- What is the outlook for NG prices? What are they going to do in relation to diesel prices? Based on current EIA drilling cost estimates and natural gas price projections, the differential will retreat a bit from its 2011 spread, but natural gas is expected to retain its significant cost advantage over crude oil for the foreseeable future. For reference, current price projections call for $4.50 to $6.00 per Mcf of natural gas, while crude oil is expected to range from $90.00 to $95.00 per barrel. From 1994 to 2005, the ratio between crude and natural gas prices averaged about a factor of 8 times. Following the discovery of significant natural gas reserves, the ratio jumped to 16 in the 2007 to 2011 timeframe, actually hitting 24 in 2011.

- Will the recovery of manufacturing and the real estate market cause NG prices to rise as demand increases? The initial answer is maybe yes. However, as NG prices rise, more wells will come back online, increasing output and once again exerting downward pressure on prices.

LEGISLATION/TAXING/INCENTIVES

- What are the long-term taxing plans for NG? Currently, the national tax charged on natural gas at commercial stations is roughly equivalent on a volume basis to that paid for diesel fuel. There is a common misconception that natural gas as a vehicle fuel is not taxed. That may be true for some private stations, but not commercial stations. Presently, 34 of the lower 48 U.S. states charge fuel taxes on LNG, while 38 tax CNG usage in commercial vehicles. Only two Canadian provinces tax LNG and CNG. For a complete list of state and province tax rates on diesel, LNG and CNG used by commercial vehicles in interstate travel, query the following web page for the most recent quarter: [http://www.iftach.org/taxmatrix3/choose_tableq2.php](http://www.iftach.org/taxmatrix3/choose_tableq2.php).

- What is the outlook for government (national, state, local) incentives? Incentives currently exist for some vehicles, such as transit buses. In our analysis, we have conservatively
assumed there will be no additional government assistance. Should such funds become available, they will only serve to increase the attractiveness of natural gas and shorten the payback period.

- In a related question, one of the panelists asked whether the availability of government subsidies for equipment is a driver for potential purchasers or not? The response to this question is truly dependent on each respondent. Some are not influenced by the presence or absence of subsidies, preferring to be more conservative in their analysis. Others depend on subsidies in order to meet their ROI hurdles. Potential natural gas customers would be well advised to consider a more conservative, “no subsidy” scenario as they study their options.

- What is happening with the 2013 opt-in greenhouse gas legislation? What will the effect be? Trucking largely dodged a bullet as far as GHG regulations are concerned. New fuel efficiency standards largely address GHG emissions with minimal incremental cost. At the same time, the improved fuel economy is expected to provide a quick payback of the additional cost. Natural gas engines will incur no additional cost to meet the standards, thanks to their cleaner burning characteristics. The bottom line is that there will be little or no identifiable difference in the cost of meeting the new standard.

SECONDARY MARKET

- What is the outlook of the future secondary market? Currently, there are a limited number of natural gas powered commercial vehicles in operation and even fewer that have started to make their way into the secondary market. If previous emission equipment changes are any indication of how the used truck market will react to natural gas trucks, adoption will be slower than new truck sales. The existence of niche markets, such as port dray operators, may provide an excellent outlet for used equipment. The wildcard with natural gas is the superior cost advantage. Besides cost, proximity to refueling stations will be another determining factor for the subsequent buyer.

- Will a NG vehicle have lower or higher demand than comparable diesel for the typical secondary market buyer? Initially, demand will probably be lower, but as the secondary market becomes more educated about and comfortable with natural gas, demand will increase. This is likely to be a slow transition, lagging behind the adoption curve on the new truck side by several years. However, since there will be so few natural gas units available over the first few years, placement of those units should not be difficult.

- What is the life cycle depreciation? We are not aware of any changes in depreciation schedule for natural gas powered trucks. However, because of the incremental purchase price, the amount of depreciation expense should increase on an absolute basis. As with any tax related item, potential purchasers should check with their tax accountants for the most up-to-date accounting practices.

MAINTENANCE SCHEDULES AND COSTS

- What are the maintenance costs and schedules comparisons between NG and diesel? The vast majority of the hardware of diesel and natural gas engines is common and the maintenance needs are very similar. Recommended maintenance schedules vary by engine manufacturer, so it is best to follow their specific recommendations, but in general maintenance intervals are the same for natural gas and diesel engines. There is some work being done to evaluate extending engine oil drain intervals, since natural gas is a cleaner burning fuel and leaves behind significantly less carbon in the engine. Again, the engine maker is the definitive source on this topic.

- How can we present ROI as a real plan so management knows how to press on given our specific operating environment? A good first step is our payback calculator. It allows for the input of fifteen variables to determine whether the level of investment is appropriate. As with any large capital investment, a thorough understanding of the proposed project is imperative. This paper should provide an excellent framework for the various facets to be addressed in such an analysis.
What does the infrastructure cost to be in the NG business? As one might imagine, infrastructure costs are scalable. Factors that determine cost are the amount and type of natural gas to be used in refueling, as well as the rate at which refueling needs to take place. Natural gas suppliers are probably the best source of information on this topic. For commercial refueling stations, cost estimates range from $400,000 to $2.5 million, but the final cost is truly dependent on throughput. Another factor to keep in mind is the cost of installing a diesel refueling station and then understanding the incremental cost difference.

What is the fuel savings NG vs. diesel long term? The answer to this question depends on a number of variables, including the costs of the respective fuels, the efficiency of the vehicle using them and the number of miles travelled. On page 75 of the report, we present an annual fuel cost comparison. In that table, we show annual cost savings ranging from $15,000 to $21,000, with five year costs saving of more than $100,000 possible.

OEM & SUPPLIER RELATED QUESTIONS: PERFORMANCE & OPTIONS

Has anyone conducted an objective and scientifically based well to wheel emissions analysis? The panelist that asked this question explained that they had attended a meeting with [engine manufacturer] that said there is no advantage to emissions to NG, that the 2010 emission diesels are so clean there is no advantage. There is no doubt engine manufacturers have done a stellar job of cleaning up tailpipe emissions. In addition, the comments were obviously made in reference to NOx and particulate matter, ignoring impending GHG standards. Natural gas contains significantly less hydrocarbons than diesel. However, the cost to clean up those emissions, as well as the significantly lower cost of natural gas relative to diesel, is where the opportunity lies when considering natural gas. To answer the original question, we are not aware of any comprehensive well to wheel emissions studies that have been published.

What are the emissions of NG? Will there be future legislation of currently unregulated emissions? According to the U.S. Department of Energy, tailpipe emissions of primary concern include the regulated emissions of hydrocarbons, oxides of nitrogen (NOx), carbon monoxide (CO), as well as carbon dioxide (CO₂). At the tailpipe, additional regulation is unlikely. There are concerns about emissions at the extraction, transportation, storage and filling operations that may be the subject of future regulation.

Is the current availability of natural gas engines and trucks a barrier to adoption? The panelist that asked this question aptly pointed out that the current product offerings are limited. This is an accurate portrayal, but change is taking place on that front and at an unprecedented rate. Chapters 4 and 7 contain a list of the products that are currently available, as well as a rundown of recent product announcements.

Who is doing what from an engine builder perspective and who is using CNG/LNG and why? This came as a single question, so it is not entirely clear if the panelist was asking which fleets are using CNG/LNG or which engine manufacturers are producing CNG/LNG. To answer the first part of the question, the two production ready natural gas engines used in heavy truck application available today are the Cummins Westport 8.9L spark ignited CNG/LNG engine and the Westport Innovations 15L dual fuel diesel/LNG. So far, fuel choice among carriers has lined up along availability of the respective fuel type, location of/and distance between refueling stops, refueling time requirements. Range of operations seems to be the overriding determinant. LNG is much denser than CNG, and therefore, more energy can be carried on board in the same amount of space.

Are there other engine manufacturers closing in on Westport from a natural gas development standpoint? While Westport is a prominent figure in the natural gas engine world, there are several other engine manufacturers in the space. Cummins, both independently and in a joint venture with Westport, has several natural gas products. In addition, Navistar has announced plans to develop a 13L natural gas engine in 2013. In addition, Volvo plans to
bring a dimethyl ether (DME) engine to the U.S. in 2014. DME is a natural gas derivative product. It is also likely that the North American CV market could see entrants from outside its borders introduce natural gas engines.

- What is the timing of [supplier] tank production and availability? What other storage technologies are coming in 2013? 2014? The panelist who asked this question said they had heard that in Q4’12 [supplier] will have NG tanks available. This topic was outside of the scope of the project, so we do not have a specific response. However, as the market begins increasing in size, it is only natural that major components and suppliers will develop in tandem. Previously, offshore tank manufacturers tested the waters in the U.S. market, but volumes were not sufficient to justify participation. As the level of activity increases, it is reasonable to expect the potential for offshore suppliers to reconsider their decision to enter the U.S. market. Secondarily, are there any other tank manufacturers jumping into the game? More competition will push the prices down and this is important.

- What is the scale of the volume of units to bring the costs down enough to make it more affordable for people? Inherent in this question is the belief that natural gas powered trucks are not currently affordable. As our payback calculator shows, this is not necessarily an accurate perception. As with any new product introduction, particularly when new technology is involved, costs are higher until some degree of critical mass is attained. In the case of NGVs, this is a win-win proposition. Because the trucks already have a reasonable payback period, lowering the cost will only shorten an already attractive investment opportunity.

How will natural gas powered trucks perform in different operating conditions, such as over mountains in snow, or on hot, dry pavement? There are no limitations for natural gas trucks that would cause them to perform any differently in extreme conditions than their diesel powered counterparts. One advantage they have would be in cold climates where diesel fuel is susceptible to gelling. Natural gas engines are also easier to start in cold weather. Another difference is that they are quieter than diesel engines. In reality, most drivers probably would not even notice the difference.

- Will buyers get the same engine performance or will their natural gas trucks be a hazard and their drivers upset because of the torque and speed loss? The key to this concern is proper spec’ing. On a horsepower and torque basis, as long as the natural gas truck is comparably spec’ed to the legacy truck, the performance will be no different.
ANSWERS TO UNASKED QUESTIONS

- Which fuel should I use, CNG or LNG? It depends. There are pros and cons to each. These include:

CNG-Cons
- Heavier fuel tanks and more vehicle weight
- Longer fuel tank fill times for fast fill
- A separate CNG compression/fueling station can cost more than delivered LNG
- Generally, less range than with LNG

CNG-Pros
- Least costly per DGE purchased as it doesn’t need to be supercooled
- Slow fuel fill stations cost less
- Fuel doesn’t vent off, as can LNG
- If tractor weight is not a problem, then, CNG might be the least costly fuel tank(s) solution
- Several tank weight and cost options

LNG-Cons
- On DGE basis, more costly than CNG
- Fuel can vent off if not used for several days
- Fuel tank(s) can be more expensive than CNG
- Only fuel you can use with a HPDI system

LNG-Pros
- If an underground pipeline supply of natural gas is not available, LNG can be delivered by tanker just like diesel
- Fastest fueling times, about the same as diesel fuel
- Could be that more LNG fueling stations are being built and planned along interstate system
- Generally, LNG fuel allows for the most fuel on board the truck

- Isn’t methane (natural gas) damaging to the atmosphere? Yes, it is but natural gas engines don’t give off methane as they burn the methane gas. Natural gas engines don’t add to or detract from the methane found underground, in swamps, or around refuse sites. In fact, if we convert the methane found at U.S. refuse sites, we reduce what would vent into the atmosphere and find a source for additional natural gas fuel.

- What about the long term price of natural gas? We expect the price of natural gas to fluctuate in small amounts but not be subject to wide swings. Compared to the prospects for the price of diesel fuel, the price of natural gas is projected to be less in long term comparisons. The vast quantity of natural gas recently found by frac’ing can hold future price increases in check. The same can’t be said for imported petroleum refined into diesel fuel.

- Aren’t natural gas engines less powerful on the same displacement size comparison with diesels and aren’t they less efficient? Natural gas engines are less powerful and less efficient on a same sized engine displacement comparison than diesels. Their advantage comes into play in that soon to be released natural gas engines are of increased size and displacement to provide comparable diesel-like performance with substantially lower fuel costs.

- Where is the natural gas fueling infrastructure? The existing natural gas fueling infrastructure could not support the adoption of natural gas as a transportation fuel. The announced plans to build new fueling stations in the next 18 months and the number of new fueling stations that are being built are a move in the right direction. Hopefully, the new NG powered trucks with the more powerful NG engines will match with the opening of the new fueling stations. Our forecasts reflect this orderly introduction.

- Why not have true dual fuel trucks? There are really three answers to this one question. Each depends upon the meaning of dual fuel.
  - First let’s consider a truck set up to burn either natural gas or diesel fuel but not at the same time. This question assumes that when it is necessary to refuel, you look at available options and the respective prices for fuel. No need to worry about range anxiety as you can always find some type of fuel. The problem is that you have just made some big compromises. You’ll need a truck that has one power plant but with two exhaust
systems. One system will have a DPF (Diesel Particulate Filter) and uses DEF (Diesel Exhaust Fluid) and the other will use a simple three way catalyst. You’ll also need room on the truck for two fuel system: Diesel fuel and a natural gas system of either CNG or LNG. The use of two systems would add much weight and take valuable space on the truck or tractor or maybe even the trailer looking forward. How much payload has been lost, if any? The vehicle would need an engine of sufficient displacement that the natural gas fueled version could equal the performance of the diesel. With just one given size of displacement, it would be hard to optimize turbocharger match, piston compression ratio, valve timing, electronic calibrations and a host of other compromises. Remember, both fuel supply systems would need to independently pass existing and future emission legislation. If you could get the single displacement engine to work for both fuels, you would have a very heavy truck with two very costly non optimized power plants.

Next, if dual fuel means burning two fuels at the same time, then, you have what is known as a HPDI approach. The engine operates on compression ignition (you compress the air in the cylinder to the extent that it gets so hot the diesel fuel ignites when injected into the cylinder). In this case, a small burst of diesel fuel is injected into a cylinder of compressed air to create combustion followed by a good amount of natural gas. The mixture is about 5% diesel and 95% natural gas at full power and uses one injector to deliver both fuels at the right time. Prior to 2007, you didn’t need any exhaust aftertreatment but with 2007 and 2010 emission legislation, you needed DPF and DEF to clean the diesel combustion. The advantage of the HPDI system, such as that offered by Westport Innovation, is that the system can equal the horsepower, torque and fuel economy of the diesel engine. The disadvantage is that it costs more than a spark ignited natural gas engine primarily because of the cost and complexity of the HPDI engine fuel system. All emissions-related equipment remains.

The third dual fuel system was generally a field conversion of a diesel engine used prior to the emission legislation of 2007. The basic approach was to reduce the diesel fuel injection rate and fumigate the diesel engine’s intake manifold with a controlled amount of natural gas. The system required diesel and natural gas fuel supply tanks on the truck. When running both fuels, you could not get the full horsepower that you could with diesel only but in a cruise mode, you burned less costly natural gas rather than more expensive diesel fuel. One had to be careful not to fumigate with too much natural gas as you could get into combustion detonation and pre-ignition problems. Despite its relative simplicity, emission legislation pushed this simple approach into history. Cost effective conversions of this approach just didn’t adapt to emission law realities.
APPENDIX

Glossary of Acronyms ................................................................................................................. A-2

Reference Library ......................................................................................................................... A-3 – A-11
# GLOSSARY of ACRONYMS

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<tr>
<th>A</th>
<th>Alternative Fuels Data Center (U.S. Dept. of Energy)</th>
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<td>L</td>
<td>LNG</td>
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<td>B</td>
<td>British Thermal Unit</td>
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<tr>
<td>M</td>
<td>MMBtu</td>
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<tr>
<td>C</td>
<td>Compressed natural gas</td>
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<td>O</td>
<td>OEM</td>
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<td>D</td>
<td>Diesel exhaust fluid</td>
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<td>P</td>
<td>Pilot injection natural gas</td>
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<td>E</td>
<td>Electronic control module</td>
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<tr>
<td>S</td>
<td>Spark ignited natural gas</td>
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<td>G</td>
<td>Gasoline gallon equivalent</td>
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<td>T</td>
<td>TRR</td>
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<td>H</td>
<td>High occupancy vehicle lanes</td>
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<td>U</td>
<td>UOM</td>
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<tr>
<td>I</td>
<td>High pressure direct injection</td>
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ACT Research provides services and in-depth research to the commercial vehicle (CV) and transportation industries and supporting financial institutions. By working confidentially with all of the North American (N.A.) Classes 5-8 CV manufacturers, major trailer manufacturers, distribution networks, and transportation providers, we are able to add to our unique industry knowledge and insights.

ACT Research Co., LLC is the recognized leading publisher of commercial vehicle (CV) industry data, market analysis and forecasting services for the North American market. Our commitment to data quality & integrity, in-depth analysis, and timeliness have made our services the industry standard.

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- Trucks

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U.S. Used Truck Market Classes 3-8

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- Intermodal Market Analysis

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