ISSUE BRIEF

Will Natural Gas Vehicles Be in Our Future?

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Alan J. Krupnick[1]

Abstract

Until recently, natural gas was an also-ran in the sweepstakes for changing the face of transportation in the United States. This is in spite of the fact that expanded reliance on natural gas vehicles (NGVs) holds the promise of reducing carbon emissions, reducing dependence on oil, and even lowering transportation costs. Recently, however, interest in natural gas as a transportation fuel has grown, as the availability of shale gas resources has dramatically expanded and gasoline prices have spiked.

The purpose of this issue brief is to investigate the evidence for and against NGVs as a reasonable option to their closest alternatives, focusing primarily on 1) light-duty vehicles (LDVs) running on compressed natural gas (CNG), compared to conventional gasoline vehicles and electric hybrids, and 2) heavy-duty trucks running on liquefied natural gas (LNG), compared to diesel trucks. Comparisons are based on several original analyses, using data from the National Energy Modeling System (as modified by RFF), automobile manufacturers, and other key sources.

The results suggest that LNG trucks can, under certain conditions, be a good deal for society in reducing oil and CO_2 emissions with reasonably competitive cost-effectiveness, even without government subsidies or mandates. Indeed, under certain more restrictive conditions, they can have attractive payback periods even without government subsidies. I also note that infrastructure issues may be less challenging than commonly thought because the interstate trucking industry is moving increasingly from a long-haul route structure to a "hub and spoke" structure—a development that could facilitate more judicious placement of LNG refueling stations and therefore make use of LNG trucks more prevalent. For LDVs, however, natural gas as

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a fuel remains a tough sell without policies in place that price carbon or otherwise favor gas over oil.

Introduction

The short answer to the title of this Issue Brief is self-evident—yes, because natural gas vehicles (NGVs) are already part of our present. However, NGV penetration in the United States has been limited for the most part to small market niches—medium to heavy-duty fleet vehicles, such as buses, trash trucks, and single unit delivery truck fleets, such as those from Fed Ex and UPS (and most recently, AT&T[2]). The huge light-duty vehicle market currently has only one entrant—the Civic GX by Honda (and this is limited to four states). The real question is: will the reach of natural gas vehicles be extended beyond these niches—whether by the market, because such vehicles are economic on their own, or through government subsidies and mandates?

Why even ask the question given the dominance of gasoline and diesel vehicles, the growing penetration of gasoline-electric hybrids, the recent and much hyped introduction of the all-electric vehicles—Nissan Leaf and Chevy Volt—and mandates for the use of second generation biofuels? The reasons are cheap fuel, low carbon fuel, and energy security. Natural gas has recently become much more available domestically following the use of hydraulic fracturing and horizontal drilling techniques to extract shale gas from places such as the Marcellus Shale formation in the Appalachian states. And with gasoline prices at about $4 per gallon, natural gas looks ever more attractive. For the reason home-grown natural gas would likely substitute for gasoline and diesel fuel (although perhaps some substitution could take place with coal and other fuels generating electricity for vehicles), there would be energy security benefits as well, As for biofuels, the mandates apply only to the light-duty segment of the market and, already, penetration is behind schedule. In terms of lifecycle carbon dioxide (CO_2)-equivalent emissions, natural gas appears to hold a 20-30 percent advantage [3] with a much larger advantage when methane is drawn from renewable feedstocks.

Natural gas in its energy-dense liquefied form (LNG) is really the only option beyond diesel for heavy-duty applications. Batteries lack the necessary punch, while these trucks are large enough to serve as an economical platform for the equipment needed to deliver LNG to the engine. A last reason—and perhaps the most important, is simply that natural gas vehicles have made much more of an impact elsewhere, so why not here?[4] Natural gas vehicles (NGVs) have been a part of

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[2] See Taschler (2011)

[3] For a contrary view, see Howarth et al. (2011). See Krupnick (2010) for detailed estimates from several studies.

[4] In 2007, an analysis conducted by Sonia Yeh at the Institute of Transportation Studies, at the University of California Davis, compared the adoption of NGVs across eight countries. Compared to other countries the United States faired poorly with regard to the vehicle payback period, an estimated seven years between 2000-2005, vehicle to fueling station ratio, and retail fuel price ratio. (Yeh 2007).

global vehicle fleets for decades, with an estimated 13 million on the road worldwide.[5] Currently, the United States is considerably behind countries such as Argentina, Brazil, Italy, and India, and ranks 14th globally in number of NGVs on the road.[6] However, between 1999 and 2009 U.S. domestic consumption of natural gas in the transportation sector tripled.[7] Our estimated 110,000 NG vehicles[8] represent a small fraction of the more than 250 million vehicles in the United States.

Penetration of these vehicles has resisted federal interventions. The Energy Tax Policy Act of 2005 (PL 109–58) provided an income tax credit for the purchase of a new, dedicated alternative fuel vehicle of up to 50 percent of the incremental cost of the vehicle, plus an additional 30 percent if the vehicle met certain tighter emission standards. These credits ranged from $2,500 to $32,000 depending on the size of the vehicle. However, the credit was only effective on purchases made after December 31, 2005 and expired on December 31, 2010[9].

Additionally, in August 2009, the Department of Energy announced that funding for natural gas technologies and fueling stations would be included in a $300 million grant under the American Recovery and Reinvestment Act for state and local governments (PL 111–5). However, the most recent development is the introduction of H.R. 1380, the New Alternative Transportation to Give Americans Solutions (NAT GAS) Act of 2011, on April 6, and 2011 to Congress.[10] This proposed legislation offers tax credits for new NGVs at the retail and manufacturing ends, commercial and residential refueling infrastructure and the gas itself,[11]

States and localities have also intervened. Due in part to air quality management district regulations, 65 percent of all South Coast Air Basin transit buses are now fueled by natural gas. The San Pedro Bay Clean Air Action Plan (CAAP) that was approved in late 2006 includes a program to replace all diesel trucks based in the ports of Los Angeles and Long Beach with clean alternatives, such as LNG-fueled vehicles, within five years. LNG-fueled 18-wheelers have a

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[5] NGVA (2011)

[6] Ibid.

[7] Bryce (2011)

[8] http://www.detnews.com/article/20090709/AUTO01/907090403/Bill-would-boost-natural-gas-vehicles?imw=Y

[9] PL 109–58 also provided for a tax credit of fifty cents per gasoline-gallon-equivalent of CNG or liquid gallon of LNG for the sale of CNG and LNG for use as a motor vehicle fuel. The credit began on October 1, 2006 and has recently expired. Note that this rebate (which is over twice the excise tax rate paid now), was to the seller, not the buyer. It is not clear if this could be paid to the ultimate seller – in which case an owner of a trucking company could have qualified for the rebate – or to the wholesaler.

[10] See Govtrack (2011)

[11] Specifically, the NAT GAS ACT offers: 1.) a tax credit for new NGV purchases, up to 80% of the price differential which translates into a maximum of $7,500 for LDVs and $64,000 for HDVs; 2.) an infrastructure tax credit of 50% of the cost of a new station up to a maximum of $100,000; 3.) an extension of the 50-cent per gallon fuel tax credit; 4.) a $2,000 tax credit to home refueling units; 4.) and, a tax credit to NGV manufacturers.[11] This bill currently has bipartisan support and has been referred to the House Energy and Commerce Committee. Gray (2011)

presence here as well.[12] Currently, there are 879 natural gas fueled trucks in the Drayage Truck Registry (DTR), which represents 7 percent of container trips in San Pedro Bay.[13]

Utah has been promoting the use of natural gas vehicles, including private automobiles, by working with a local gas utility to build the fueling infrastructure. Trailing California and New York, Utah currently is one of the top states in number of CNG refueling stations, with 73.[14] In Colorado, the city of Grand Junction opened its first CNG refueling station in April 2011 completing a chain of CNG stations from California to Denver.[15] And in Pennsylvania, with interest in all things burning natural gas has risen, Pennsylvania House of Representatives introduced a package of legislation aimed at providing $47.5 million in tax incentives, grants and loans to promote investment in natural gas truck and bus fleets for municipalities and businesses.[16]

Considering LDV manufacturers, Honda plans to significantly expand the availability of its natural gas-fueled Civic from five to over three dozen states, a Hong-Kong based company plans to build CNG/gasoline/ electric hybrids in the U.S., and Chrysler is gearing up to produce natural gas fueled LDVs. As for truck engines, competition with industry leader Westport is growing from companies such as Emission Solutions, Inc. (ESI).[17]

Yet even proponents of natural gas concede that these vehicles face significant obstacles to capturing a major share of various market segments. Irrespective of vehicle type, there are concerns regarding economics—natural gas vehicles cost more, although fuel costs are likely to be lower—as well as concerns about safety and availability of refueling stations.[18] The latter is the "chicken and egg" problem: vehicle users will not buy NGVs until they believe there are enough refueling stations, but there is little motivation to build an NGV refueling infrastructure until a sufficient number of vehicle owners demand the fuel. There are also concerns about cruising range and cabin space of light-duty vehicles.

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[12] See San Pedro Bay Clean Air Action Plan (2011).
[13] CAAP (2011)
[14] AFDC (2011)
[15] Cianca (2011)
[16] The Marcellus Shale Coalition, a natural gas trade group in Pennsylvania, released a study in April 2011 to spearhead a campaign for 17 new refueling stations statewide and subsidies for a proposed 850 new natural gas HDVs for an estimated $208 million.(Gladstein, Neandross & Associates, 2011)
[17] ESI has recently developed the natural gas-fueled Phoenix 7.6L, a 300hp rework of the heavy-duty Navistar MaxxforceDT diesel engine. Currently, ESI and has plans to begin sales of the 375hp Phoenix 9.3L, project development on the T444E 7.3L, and R&D on a 475hp Phoenix 13L in the third quarter of 2011 (Turner 2010).
[18] There are only around 841 CNG fueling stations currently operating in the United States, along with 41 LNG stations (32 of which are in California) (AFDC, 2010), compared to over 180,000 gasoline stations, which also may sell diesel fuel and include around 4,000 truck stops selling diesel fuel. Trucks often travel predictable routes, meaning that the infrastructure for a CNG truck fleet could be concentrated in certain specified areas, so long as they were near gas pipelines, whereas the widespread use of CNG in passenger cars would require a much more extensive and costly refueling infrastructure. (AFDC, 2011)

In this Issue Brief, we investigate the evidence for and against natural gas vehicles as a reasonable option to their closest alternatives. We examine the use of vehicles that are powered by compressed natural gas (CNG), natural gas in its gaseous state that is compressed by high pressure, or liquefied natural gas (LNG), natural gas that has been cooled and condensed into liquid form.

What are the Most Promising Segments of the Market?

LIGHT-DUTY VEHICLES (LDVS)

It is useful to distinguish between privately owned or leased vehicles and vehicles within fleets owned or leased by businesses because businesses with large numbers of natural gas vehicles have an economic incentive to build or otherwise acquire access to refueling stations.

Private LDVs

Some of the issues related to penetration of private LDVs can be seen from using Honda's own website to compare their 2011 model year natural gas vehicle (the Civic GX Sedan) to a comparably equipped Honda Civic sedan (the LX-S automatic transmission), and their Civic Hybrid (CVT AT-PZEV). Table 1 displays the relative differences in characteristics and costs between these models.

These otherwise comparable vehicles differ in their price and (until January 2011) eligibility for a government subsidy, repair costs, fuel economy, fuel capacity, range, cargo volume and availability. Without a subsidy (the appropriate way to compare the costs of vehicles from society's point of view), the natural gas vehicle is more expensive than the hybrid, but substantially (32 percent) more expensive than the gasoline version. Its maintenance and repair costs are also more expensive than those for the other vehicles, over 50 percent more than the gasoline-powered version.[19]

The fuel economy for the NGV is about the same as that of the gasoline alternative (and of course far lower than the hybrid). Because compressed natural gas has such a low energy density and is under pressure, fuel tanks are large and heavy compared to the other vehicle types. Thus, cargo space is dramatically lower (50 percent lower) than a gasoline vehicle, as is its range of only 218 miles, compared to 383 miles for the comparable gasoline vehicle and 504 miles for the hybrid.

Given some of these cost differences and market prices for the fuel (we assume the current $1.50/gge advantage for natural gas over gasoline), we can compute the annualized costs for

[19] These estimates are taken from Honda's own site. A similar comparison (Goulding et al., 2010) uses information from a Kansas Gas Service website, which asserts that "Some fleet operators have reduced maintenance costs by as much as 40 percent by converting their vehicles to CNG."

these vehicles, with additional assumptions for period of annualization and interest rate (for illustration we assume 7 years and 6 percent). Annualization of initial investment costs should be performed over the lifetime of the vehicle, but consumers may want to use lower lifetimes, in this case, corresponding to average ownership time. These results assume gasoline is $4/gallon.

Without counting infrastructure cost or any subsidies, an HEV is almost $400/year more expensive than its gasoline-fueled counterpart, while its natural gas counterpart is almost $200 more expensive annually. Infrastructure costs for the natural gas vehicles must be considered, however, under the assumption that individuals will not purchase such vehicles unless they have access to a home fueling unit and already have natural gas in their home. These units cost $4,000 currently. We assume they last 10 years and amortize their costs at the same 6 percent interest rate. Adding this annual amount to the annual cost of a natural gas vehicle raises its cost premium over a gasoline-fueled counterpart from $200 to $721. This is basically the social cost differential of a natural gas vehicle.

Table 1. Salient Differences between NG Vehicles and Alternatives

Characteristic	Civic Natural Gas	Civic Gasoline	Civic Elec/gasoline Hybrid
MSRP (comparably equipped)	$26,240	$19,905	$24,700
Subsidy (eliminated 1/2011)	$4,000	0	0
5-yr maintenance and repair	$3,321	$2,145	$2,340
Combined FE	28	29	41
Fuel Capacity (gge)	7.8	13.2	12.3
Range	218	383	504
Cargo Volume (ft3)	6	12	10.4
Availability	CA, NY, UT, OK*	50 states	50 states
Total Costs/yr Differential (without infrastructure)	$200	-	$400
Total Costs/yr Differential (with infrastructure)	$721	-	$400
With $2000 infrastructure subsidy and $4000 vehicle subsidy	($100)	-	$400

Note: Vehicle data obtained from Honda's website: http://automobiles.honda.com/tools/compare/
*Honda plans for availability to increase in 2011.

From the individual's perspective, we need to consider the $4,000 subsidy for the investment cost (which ran out at the end of 2010, but is in new bills to reinstate), the $2000 subsidy for home charging stations and the annual cost of the loan (which we assume is for a five year period). After these adjustments, amortized costs are about $100 less than a gasoline vehicle. As noted above, however, natural gas vehicles have much lower range, less trunk space and in almost all U.S. locations, could not reliably be used for long distance travel because home refueling would be impossible. It remains to be seen if these restrictions are worth more to consumers than $100 per year.

Fleet LDVs

Light duty fleet vehicles represent a relatively small market, with fleet cars accounting for only 4.3 million or 3.2 percent of the 135.9 million cars registered in the United States and fleet trucks being as numerous (Table 2). This may understate the importance of the light-duty fleet market, however, as fleet vehicles travel more miles on average than privately owned vehicles (e.g., 26,000 miles for fleet cars annually compared to around 12,000 for individual cars), and tend to be replaced more frequently. A subset of the fleet vehicles—taxis—travels from 80,000 to 100,000 miles per year.

Table 2. Annual Oil Consumption of Vehicles Targeted for Natural Gas Use

Vehicle type	Average annual miles	Number of vehicles	Average fuel economy	Implied fuel consumption
Business: fleet car	26,196	4,230,791	22.4	4,947,758,975
Business: fleet truck <19,500 lbs. gross vehicle weight (GWV)	27,372	4,182,765	18	6,360,591,310
Federal government: sedan/station wagon	12,372	111,209	22.4	61,423,114
Federal government: SUV	10,064	120,004	18	67,095,570
Federal government: ambulance	4,967	1,982	18	546,922
Federal government: light truck	5,874	283,835	18	92,624,822
Federal government: medium truck (8,500–26,000 lbs. GVW)	6,418	84,414	14	38,697,789

Total Gasoline	11,568,738,501
Barrels of Oil	275,446,155

Source: U.S. Department of Energy. 2008. *Transportation Energy Data Book*.

According to the U.S. Department of Energy's (DOE) *Transportation Energy Data Book* (2008) light-duty fleet vehicles consumed roughly 11.6 billion gallons of gasoline last year (based on average annual mileage, numbers of fleet vehicles, and average fuel economy statistics in the TEDB). This is equivalent to the gasoline produced from 276 million barrels at 42 gallons per barrel. For contrast, total U.S. gasoline consumption is 3.290 billion barrels/year.

MEDIUM DUTY: SINGLE-UNIT TRUCKS

The Federal Highway Administration estimates that there were 8.3 million single-unit trucks (2 axles, at least 6 tires, or a gross vehicle weight of over 10,000 lbs) registered in the United States in 2009[20]. A few examples of single-unit trucks include FedEx and UPS step vans and rental trucks. The single-unit truck segment has a reported average fuel economy of 7.4 mpg and accounted for consumption of an estimated 16.3 billion gallons of diesel fuel in 2009.[21] Natural gas is already penetrating this market segment (albeit slowly), so is in less need of analysis.

BUSES AND MUNICIPAL TRUCKS

Buses and garbage trucks represent a limited market, with only a little more than 68,000 transit buses[22], 480,000 school buses[23], and somewhat more than 136,000 refuse trucks operating in the country[24]. However, because of the current emphasis on reducing smog-forming emissions, these vehicles have been targeted for natural gas use more because of their presence in urban environments than for their importance in the overall U.S. vehicle fleet. Currently, there are about 12,000 natural gas fueled transit buses in operation.[25] Still, transit buses and garbage trucks can use 10,000 to 15,000 gallons of fuel per year (garbage trucks tend to be at the low end of this range), so switching these fleets to natural gas can be economically favorable. [26]

Various public school districts have converted their fleets to run on natural gas. After taking part in a pilot alternative fuel vehicles project in the late 1980s, Tulsa Public School District in Tulsa, Oklahoma, now has a fleet of 190 CNG vehicles. In 2005, the Tucson Unified School District in Arizona purchased 70 new CNG buses. The Union of Concerned Scientists reports that 130 school districts in 17 states currently use alternative fuel buses, a large number of which run on natural gas.[27]

COMBINATION TRUCKS

Combination trucks—those designed for use with one or more trailers—are driven in both urban and rural areas. They account for the majority of heavy-duty vehicle miles travelled, and form an even larger share of heavy-duty vehicle diesel consumption. The 2.6 million registered combination trucks in the United States accounted for a total 167 billion miles driven in 2009.[28] At an average fuel economy of 5.0 to 6.0 mpg, combination trucks use an estimated 28 billion gallons of diesel annually, which is equivalent to 640 million barrels of oil.[29] For contrast, total U.S. diesel

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[20] FHWA (2009)
[21] Using registered trucks to cacluate the average fuel economy for the single-unit truck segement is not ideal because not all registered trucks are regularly drivenFHWA (2009).
[22] FTA (2008)
[23] ASBC (2008)
[24] Cannon (2005)
[25] EIA, AEO2010.
[26] See Caley (2010).
[27] Union of Concerned Scientists (2004)
[28] FHWA (2009)
[29] Ibid.

consumption was 1.2 billion barrels per year in 2008. The highest mileage trucks are best able to benefit from the fuel price advantage of natural gas over diesel.[30]

Are Natural Gas-Fueled Heavy-Duty Trucks Economic?

Conclusions about whether heavy-duty natural gas-fueled trucks are economic depend on the definition of economic. The narrowest definition would recognize only the net present discounted value (evaluated at the market rate of discount) of the long-term fuel cost savings from reliance on natural gas over the more costly diesel fuel, minus the greater investment costs of a natural gas-fueled truck compared to a diesel truck. A finding of positive net benefits means that it is in the private interests of truck buyers to buy a natural gas-fueled vehicle. A broader definition of economic would allow for adjustments to this calculation based on market failures (e.g., myopia of would-be buyers who insist on three or four-year payback on their investments) and imply a role for government in subsidizing or otherwise incentivizing the purchase of such vehicles. Consistent with our treatment of market failures in energy efficiency in the RFF-NEPI study (Krupnick et al, 2010), we would evaluate the fuel savings with a lower discount rate than is implied by the market, reflecting the social interests in seeing such penetration . Government intervention could also be warranted to account for uninternalized externalities. These could be network externalities associated with the lack of a refueling infrastructure, for instance, or even air pollution externalities.

In Krupnick (2010) the above calculations were made using estimates of costs and prices from the literature. These included differentials in the vehicle purchase price and fuel prices[31], and other factors affected cost, such as the vehicle lifetime vehicle miles traveled (VMT) and fuel economy (all held constant across vehicle types).

Below, we provide the assumptions we used to calculate payback periods (i.e., the number of years of fuel savings (or the payback period) that will exactly offset the higher up-front costs of an LNG heavy-duty truck) for investments in a heavy-duty LNG truck relative to a diesel truck and then report on those results. In addition, for specific scenarios for the national penetration of LNG trucks, we report on runs of the National Energy Modeling System (NEMS) modified by RFF (NEMS-RFF) to show outcomes for welfare costs, oil use and CO_2 reductions, with both low (310 tcf) and high (616 tcf) estimates of shale gas resources. We developed a “bounding” scenario that assumes that 10 percent of the new class 7 and 8 vehicles will be powered by natural gas in 2011,

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[30] Taxis, because of their high mileage, could also operate more economically on natural gas than most light-duty vehicles could. Conversely, school buses may not be good candidates for natural gas because of their relatively low mileage.

[31] In performing our analyses, we did not include the costs of building or converting refueling infrastructure. We assumed these costs would be included in the price of natural gas at the fuel pump. Thus, one can implicitly address such costs by manipulating fuel price differentials between diesel and natural gas.

20 percent of new purchases in 2012 will be LNG powered, and so on, so that by 2020 and for the following 10 years, every new class 7 and 8 truck purchased would be powered by CNG/LNG.[32]

FUEL COSTS

Expectations about future fuel costs of natural gas and diesel would drive market purchase decisions. Such expectations would typically be based on historical prices, the current price and expectations and about future events. As a benchmark, a long-haul heavy-duty truck traveling 70,000 miles a year getting five miles per gallon would be using 14,000 gallons and thus saving $14,000 at a $1/gallon equivalent fuel price differential.

Advocates for natural gas vehicles cite historic figures to claim differentials with diesel in the $1.70 per gallon equivalent range. The Natural Gas Vehicle Association claims on their website that the fuel costs of using natural gas instead of diesel can be "one-third lower." Daimler–Chrysler, for their new series of Class 8 LNG trucks, cites a savings of only $6,000 per year, but the press release refers to trucks working in the Port of Los Angeles so their mileage may be very limited, so it is not possible to estimate the implicit price differential.[33]

In fact, in California, where truckers can fill up at several stations with LNG, per diesel equivalent LNG is $0.75/gallon equivalent cheaper for the independent trucker and $1/gallon cheaper for the fleet vehicle.[34] Indeed, when oil prices were at their highest in 2008 and diesel was $4.75/gallon, LNG was $2/gallon cheaper than diesel even though natural gas was priced relatively high at $11–$13 per 1,000 cubic feet (mcf) of gas.[35] Currently, average monthly natural gas prices at Henry Hub are hovering around $4 per mcf.[36] So price differentials can be quite large.[37]

There are reasons to think that the recent fuel price gap could remain or widen in the future. Greater accessibility and technological advances in recovering shale gas could keep prices of LNG stable or even drive them lower, while prices for oil and, therefore, diesel fuel are believed to be on an upward trend. A recent presentation by IHS Global Insight (2010) shows that over the long term the ratio of oil to gas prices may rise to about three to one between now and 2030.[38]

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[32] We assume a penetration of LNG because the NEMS model does not incorporate consumer decisions to purchase any vehicle powered by either CNG or LNG. In this scenario, the stock of Class 7 and 8 freight trucks fueled by LNG is projected to rise to 5.15 million vehicles by 2030, with another 1.9 million diesel vehicles still remaining in the stock. This scenario results in 32 percent of the heavy-duty truck fleet fueled by natural gas in 2020, rising to 73 percent by 2030.
[33] Abuelsamid (2009)
[34] Interview with Mitchell Pratt, Clean Energy Inc., November 17, 2009.
[35] EIA (2008)
[36] EIA (2011)
[37] Irrespective of these price differentials, it is appropriate to consider any tax benefits for natural gas over diesel. There are currently no such benefits. Until the end of 2009, LNG sellers were eligible for a credit of fifty cents per gallon from the federal government (and there are state programs providing per-gallon credits against excise taxes). It is likely that some of these benefits would have been passed on in lower fuel prices.
[38] Presentation by Mary Novak, IHS Global Insight, at the EIA 2010 Energy Conference, April 6–7, 2010, Washington, DC.

However, natural gas prices have a history of instability and CNG has, at times, been more expensive per gallon equivalent than its diesel counterpart.

In the analysis below, we set the price differential at $0.50, $1.00 and $1.50 per diesel gallon equivalent.

NEW VEHICLE COSTS

Several papers address the price differentials without subsidies for a Class 8 truck fueled by either diesel or natural gas. According to estimates on line and in conversations with experts, the differential ranges from $70,000 to $100,000 (for early models) more than the price of a diesel truck of about $100,000.[39] Detailed information on vehicle prices puts the cost differential at $70,000 for a Westport compression-type LNG engine, with a newer technology relying on an 85 percent LNG /15 percent diesel fuel mix, selling for only $35,000–$40,000 above its diesel counterpart[40]. The price differential for a smaller version of the Class 8 truck (termed a "Baby 8") or a Class 7 truck (both using spark plug technology) is in the $40,000 range.

Expected future new vehicle cost differentials may be lower. NGVs have not yet benefited from economies of scale as gasoline and diesel vehicles have, so costs might decrease significantly if demand for NGVs increases. Second, stricter standards on diesel emissions, which take effect in 2010, may raise prices on diesel vehicles. Furthermore, future costs are highly uncertain. Natural gas engine technologies are less mature than diesel and gasoline technologies, and it is uncertain which particular NG engine types will be most successful in the future. For example, as of 2010, spark-ignited, lean-burn CNG and LNG engines, which have been the most common designs, are no longer being produced because they cannot meet 2010 emission requirements. They have been replaced by stoichiometric spark-ignited engines with cooled exhaust gas recirculation (EGR). About 5,000 of these vehicles were in service as of the end of 2009. Operating in the other direction are attempts to stimulate clean diesel technologies. For instance, trucking companies can get $20,000 rebates for purchasing new clean diesel trucks operating in the Port of Los Angeles. In the analysis below, we set the investment cost differential at $35,000, $70,000 and $100,000.

MAINTENANCE COSTS

It is difficult to compare maintenance costs of new Class 7 and 8 trucks operating on diesel and natural gas because U.S. experience with these types of trucks is limited. Early experience with

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[39] Total Transportation Services recently purchased 22 additional Kenworth T800 LNG trucks to expand its fleet of 8 such trucks purchased six months before. This purchase suggests that fuel and maintenance costs were manageable (Kell-Holland, 2009).

[40] Interview with Michael Gallagher, Cummins Westport, November 2009.

single-unit trucks (Class 7) by UPS was extensive, but occurred in 2002. UPS found that maintenance costs at one facility were 29 percent higher for their CNG vehicles compared to their diesel trucks, but with greater attention to the vehicles at another facility, maintenance costs were only 6 percent greater (Chandler, et al. 2002). Evidence is mixed for transit buses and fleet vehicles as well as for long-haul trucks. Some transit bus studies show higher and others lower maintenance costs. Again, for buses, studies of comparative operating costs (fuel and maintenance costs) show costs to either be higher for NG buses or the same as for diesel buses (Hesterberg, Bunn, and Lapin 2009). By default, we assume they are equivalent.

FUEL ECONOMY

The energy content of LNG is 23 percent lower than diesel for tractor trailers, and in this range for delivery trucks and buses (Hesterberg, Bunn, and Lapin 2009). CNG and LNG fuel tanks are heavier than their diesel counterparts (adding about 500 pounds per tank, increasing truck weight and further reducing fuel economy) and the spark engines have lower efficiency than their compression-based counterparts, which in turn are more similar to a diesel engine.

According to the U.S. Department of Transportation (DOT), fuel economy of diesel Class 8 vehicles was 5.1 mpg in 2007.[41] LNG equivalent fuel economy appears to be in the same range.[42] In the analysis below we also use a range from 4.6 DEG to 5.6 DEG.

MILES PER YEAR AND VEHICLE LIFETIME

There are different estimates of how far the average class 8 vehicle is driven per year. One estimate is about 70,000 miles based on DOT data.[43] Another estimate, which uses Census data from 2002, features average VMTs of about 90,000 miles per year. Also from this source, which provides distribution data, the vehicle at the mode of the distribution is driven about 125,000 miles per year and about one-third of the fleet drives this distance or more. In the analysis below, we vary VMTs from 70,000 to 125,000 per year. As a large segment of the market apparently is in this high mileage group, and the more a truck is driven the greater the cost savings is from using natural gas, it may be that for the high mileage segment, payback periods are acceptable, whereas for the lower mileage segment of the market, they are not.

We assume VMT would not differ based on fuel use; however, the shorter range for trucks using CNG and LNG might result in fewer VMTs. For calculating fuel savings on a lifetime basis, we estimate vehicle lifetime to be 15 years,[44] based on information from the DOT. There is anecdotal

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[41] FHWA (2008). This estimate was recently revised upwards to 6.0 mpg (FHWA 2009).

[42] Interview with Mitchell Pratt, Clean Energy Inc., November 17, 2009.

[43] FHWA (2008)

[44] According to the U.S. Department of Transportation, new combination trucks (Class 8) were purchased in 2007, with registrations in 2007 of 2.221 million combination trucks. Thus, new vehicles are 6.8 percent of the fleet. Assuming this is an

information that truck owners expect their CNG and LNG vehicles to last longer but place them in the resale market after 4-5 years.[45]

Interest Rates

In the NEMS-RFF study, we used three different rates to describe rates of time preference:

- *31 percent.* This is the implicit rate of interest used by the National Energy Modeling System (NEMS).This rate derives from actual market data showing that buyers demand a payback of investment costs through fuel savings within three to four years and that fuel savings during those first few years are discounted at 10 percent. Implicitly, these factors lead to a rate of discount of 31 percent;
- *10 percent*. In the RFF/NEPI study, we use a rate of 10 percent is used to reflect partial market failure.
- *5 percent.* Social discount rates used to evaluate public projects are often in the range of 3 to 5 percent. Although the substitution of natural gas for diesel vehicles is not a public project, it can confer major public benefits in terms of emissions reductions and energy security. Of course, buyers do not use such a rate. Thus, we make calculations with this rate to illustrate the efficiency of LNG truck subsidies or mandates from society's perspective, assuming complete market failure.

Payback Periods Under Various Assumptions

In all, the above assumptions result in payback period estimates for 243 combinations, only a most reasonable few of which are shown in Table 3. About 40 percent of these 243 combinations have a payback beyond vehicle lifetime (15 years). To get to payback periods of two years or less —what is commonly believed to be what industry is looking for before it makes investments—for an investment cost difference of $70,000 and fuel economy of 5.1 miles/gallon equivalent, one needs fuel price differentials in the $1.50/gallon equivalent range, rates of interest used to evaluate multi-year fuel savings benefits of 10 percent or less, and VMTs around 125,000 per year.

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equilibrium situation, where truck retirements and purchases are equal, truck life averages 14.7 years. Industry analysts offer 18–20 years as a realistic average for truck life. (FHWA 2008)

[45] Kell-Holland (2009)

Table 3. Sensitivity of Payback Periods to Assumptions

	Vehicle Cost Differential:	$35,000			$70,000		
	Fuel Economy:	5.6 mpg	5.1 mpg	4.6 mpg	5.1 mpg		
	Vehicle Miles Traveled:	70,000			125,000	90,000	70,000
Interest Rate= 0.05	Fuel Price Diff. = $1.50	1.62	1.82	2.14	2.05	2.91	3.82
	$0.75	3.04	3.82	5.54	4.33	6.29	8.52
	$0.50	4.3	6.03	11.98	6.89	10.36	14.62
0.10	$1.50	1.73	1.95	2.31	2.22	3.22	4.36
	$0.75	3.39	4.36	6.74	5.03	7.9	11.96
	$0.50	4.99	7.48	22.72	8.88	16.54	-
0.31	$1.50	12.09	-	-	3.3	6.35	-
	$0.75	-	-	-	-	-	-
	$0.50	-	-	-	-	-	-

For lower mileage trucks (90,000 miles per year), payback periods increase about a year. This finding indicates that the high mileage part of the trucking fleet is most likely to be the best target for marketing. Halving the fuel price differential more than doubles the payback period. Halving the investment cost differential more than halves the payback period (indicating the efficacy of rebates and subsidies). A 10 percent increase in fuel economy of the LNG truck, other things equal, leads to about a 10 percent decrease in payback period at a fuel price differential of $1.50, but this improvement leads to much greater payback period reductions when the price differential is smaller (i.e., less advantage to LNG over diesel). For instance, at a price differential of only $0.75 a gallon equivalent, payback periods fall by about 20 to 25 percent. These results indicate the sensitivity of payback periods to price fluctuations as well as the efficacy of fuel price rebate programs.

Oil and Carbon Implications of Natural Gas-Fueled Heavy-Duty Truck Penetration

Start with shale gas resources assumed to be 313 tcf. Overall, we expect that LNG truck penetration replacing new diesel trucks will reduce CO_2 emissions and oil consumption. Indeed, we find that carbon emissions in the transportation sector fall 7 percent relative to reference case levels in 2030. In addition, we find, as expected, that higher demand for natural gas increases natural gas prices (16 percent in 2030), which in turn leads to higher electricity prices, reduced electricity use, reduced use of natural gas in other sectors and lower carbon emissions. As natural gas becomes more expensive, however, fuel substitution in power generation and elsewhere also occurs. This could lead to *increased* carbon emissions, depending on whether the fuel being substituted for natural gas is more or less carbon-intensive. In NEMS–RFF, the use of natural gas in electricity is largely replaced by carbon-free nuclear power, and the net effect is a 3 percent reduction in energy-related CO_2 emissions from the electricity sector. Overall, there is a net reduction in all energy-related CO_2 emissions in the U.S. of 2 percent.

Considering oil use, total petroleum consumption falls 12 percent (18 mmbd in 2030 in the reference case compared to 15.8 mmbd for the NG vehicle scenario). Imports drop by even larger amounts. This reduction in demand for oil lowers the price of diesel (13 percent, compared to the reference case in 2030) which boosts diesel fuel use by about 20 percent and ethanol use (E85) by 10 percent in the light-duty vehicle market.

COSTS AND COST-EFFECTIVENESS

To calculate costs and cost-effectiveness requires making assumptions from the list above. At a $70,000 differential investment costs, PDV of welfare costs is around $200 billion. In terms of cost-effectiveness,[46] Table 4 shows a best cost-effectiveness estimate in terms of CO_2 emissions reductions of about $80/ton, which is quite high. But in terms of oil use, the welfare cost-effectiveness is a reasonable $14–$15 per barrel.[47]

Table 4. CO_2 and Oil Reductions, Welfare Costs & Cost Effectiveness

Natural gas reserves	Reductions			LNG Truck Price Differential	Interest Rate	PDV Welfare Costs (Billions $2007)	Cost Effectiveness	
	CO_2 2010-2030 (mmt)	Oil 2010-2030 (mill. barrels)	Oil 2030 (mmbpd)				$/ton CO_2	$/Barrel Oil
AEO2009	1827.1	8030.1	4.13	$35K	0.10	77.8	32	6
					0.31	103.1	42	8
				$70K	0.10	186.4	76	14
					0.31	209.4	85	15
				$100K	0.10	277.0	112	20
					0.31	297.0	120	22
PGC	1391.2	7495.81	3.96	$35K	0.10	50.2	21	4
					0.31	92.9	39	7
				$70K	0.10	160.2	66	13
					0.31	199.5	83	16
				$100K	0.10	251.8	104	20
					0.31	286.9	119	23

[46] Cost-effectiveness is computed with effectiveness measures that estimate oil consumption reductions and CO_2 reductions out to the end of the last (2030s) cohorts lifetime (2045), assuming that aggregate emissions fall at 1/15th per year. Similarly, the costs in this calculation account for fuel savings for the vehicle purchased in 2030 over the lifetime of the vehicle (until 2045).

[47] See Krupnick (2010) for a cost-effectiveness comparison with other policies.

With larger assumed shale gas resources (616tcf), we expect natural gas prices to be lower than they would be with smaller shale gas resources to exploit. We might expect welfare costs also to be lower for the same reason. With penetration the same by assumption, we might expect overall CO_2 emissions to be higher for this case compared to that above, because of the stimulative effect of low gas prices on demand.

Table 4 shows welfare costs for the LNG truck scenario with enhanced gas resources. The roughly doubled shale gas resource assumption results in a drop in welfare costs of 5 to 14 percent and CO_2 reductions are smaller as well. CO_2, emissions fall by 1.8 billion tons cumulative over the projection period using AEO2009 assumptions and only 1.3 billion tons using the enhanced gas assumptions. Oil consumption falls by less as well. Cost-effectiveness is now more favorable at $66 per ton CO_2 but at $13 per barrel of oil reduced, only slightly better than with smaller shale gas resources assumed.

OTHER CONSIDERATIONS AFFECTING COST

Notably, the estimates above do not directly account for safety and infrastructure costs. There are arguments on both sides of the safety issue: proponents, for example, suggest that the need to contain high pressures and keep temperatures low requires extremely robust tanks and other equipment may make natural gas trucks safer in an accident than their diesel counterparts. Opponents refer to concerns about LNG storage facilities and their explosive potential. An independent review of safety concerns (Hesterberg, Bunn, and Lapin 2009) finds that diesel buses have a "significant fire and safety advantage over CNG vehicles [buses]." Whether these conclusions would hold for LNG versus diesel trucks is unclear. A government source[48] focusing on CNG *versus* LNG concludes that the latter is less corrosive but cannot take an odorant, so leaks could go undetected longer, requiring methane detectors. With respect to LNG, the very cold temperatures required for storage mean that the storage systems require intensive monitoring for tank pressure and systems to vent the gas in an emergency. While the report says that rupturing of the tanks is extremely unlikely, it also says that any resulting fire will release 60 percent more heat than from an "equivalent" gasoline tank rupture. Refueling NGVs also requires additional precautions and the rapid change in temperature from refueling can stress vehicle materials and components. The industry's response to these points is basically that the fuel is safe if the proper procedures are followed.

In addition, the cost of developing a useful natural gas refueling infrastructure could be substantial, although the interstate trucking industry is moving increasingly from a long-haul route structure to a "hub and spoke" structure, a development that could mean fewer stations

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[48] See http://www.chebeague.org/fairwinds/risks.html, which is an excerpt from a report produced by the Federal Transit Administration's Clean Air Program, Section 3.3.4 Liquified Natural Gas.

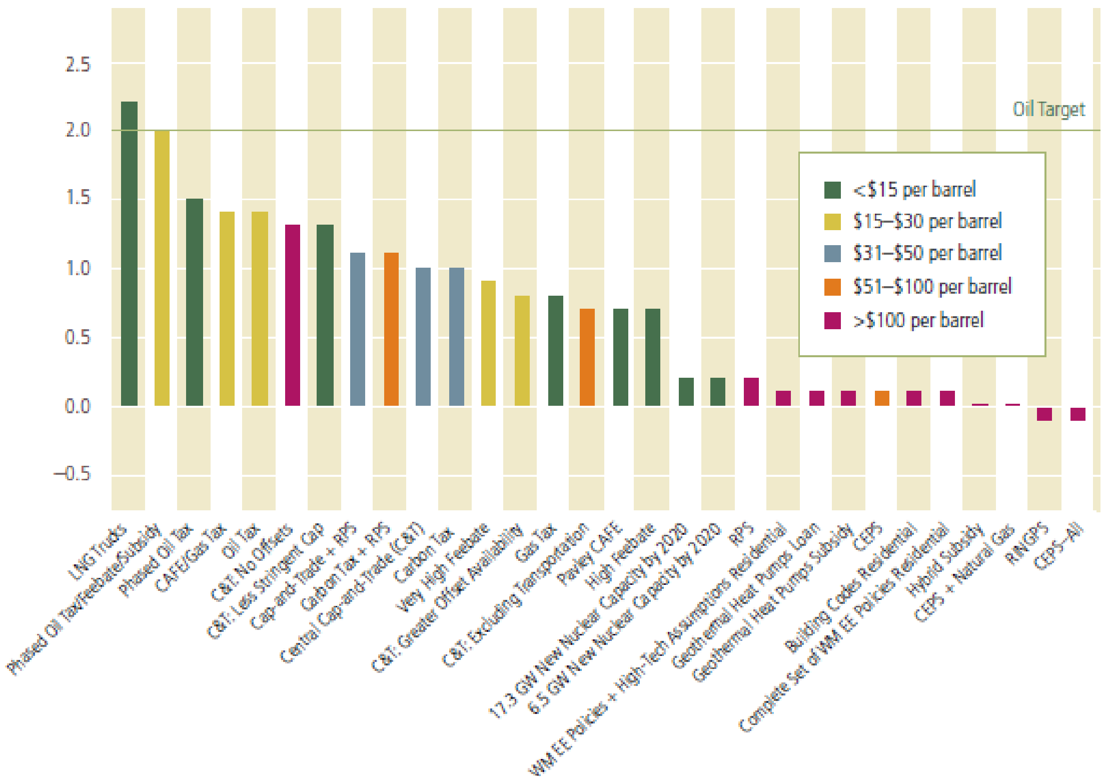
are needed (Taylor, DuCote, and Whicker, 2006) to meet refueling demand.[49] Note, however, that even if the trucking industry had adequate refueling infrastructure for long-haul trucking, there might still be economic issues concerning lack of infrastructure appropriate to the truck resale market. Trucks are sometimes taken out of the commercial trucking business and resold for use on farms and within cities after six to eight years of use. Without adequate infrastructure in rural and urban areas, this market could fail, effectively limiting the useful life of these trucks, both from a private and social perspective.

How Do LNG Truck Mandates or Subsidies Compare to Other Policies?

Using the results of the RFF-NEPI study (Krupnick et al, 2010) we can compare the performance of this aggressive LNG truck mandate to the performance of other transportation policies. Figure 1 shows this comparison (taken from table 10.1 in Krupnick et al. 2010). This "policy" results the "best combination of cost-effectiveness (under $15/barrel) and effectiveness (in reducing oil consumption) of any of the other policies modeled, including an oil tax, a gasoline tax, tighter CAFE regulations, and many other options. (Not shown from the report is figure 10.2, which shows that the truck mandate is about in the middle of the pack on the basis of CO_2 reductions and cost-effectiveness for that metric.

[49] See http://scm.ncsu.edu/public/lessons/less031014.html for a discussion of this system for major retailers in the United States. An interesting presentation by DHL (DHL FHWA Net Conference, October 20, 2004) to reconfigure their centralized system to hub and spoke can be found at www.fhwa.dot.gov/download/hep/freightplanning/talkingfreight10_20_04hp.ppt.

Figure 1. Effectiveness (in 2030) and Cost-Effectiveness (2010-2030) in Reducing Oil Consumption



Conclusions

The economics of natural gas penetration into transportation—coupled with its ability to improve energy security and reduce tailpipe CO_2 emissions and its reasonable cost-effectiveness[50,51]—makes this fuel deserving of more attention. This paper has focused particularly on the potential for LDVs to run on CNG and heavy-duty trucks to run on LNG. Honda's natural gas-fueled LDV needs investment and infrastructure subsidies at the level being discussed in Congress to compare favorably to its gasoline and hybrid counterparts. Under certain assumptions about fuel and vehicle price differentials, fuel economy, and vehicle miles traveled (such as being driven 125,000 miles per year), LNG-fueled heavy-duty trucks can return their added investment in two years, but generally, payback periods would be much longer. Additionally, this somewhat optimistic assessment does not directly account for infrastructure and safety costs.

[50] TIAX (2005) assessed the future life-cycle costs (LCC) of owning, operating, and maintaining comparable emission diesel and natural gas heavy-duty engines for refuse haulers, transit buses, and short-haul trucks. These costs are not significantly different across fuel type. After 2010, LCCs for natural gas vehicles are lower when oil prices are greater than $31 per barrel (2005$). Note that a 5 percent discount rate was used for these calculations.

[51] For analyses of cost-effectiveness of CNG buses, see Cohen (2005) and Cohen, Hammitt, and Levy (2003).

Nonetheless, a variety of developments are in play to make NGVs economical even without subsidies on the fuel or the vehicles. First, natural gas prices may remain relatively low given vast new amounts of shale gas becoming available. This means that even if a large new demand for natural gas develops, price increases may be moderate, perhaps more moderate than we forecast in NEMS–RFF. Second, technological changes for NGVs are likely to be more rapid than those for conventionally-fueled vehicles because the latter are more mature technologies. Third, if demand for NGVs does increase, economies of scale could further reduce prices. Fourth, diesel vehicles may become more cost disadvantaged in the future by a carbon policy combined with increasingly stringent air pollution regulations and tighter restrictions on fuel economy of gasoline and diesel vehicles. In short, the use of natural gas in transportation remains something worthy of significantly more attention.

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