COMPARISON OF GREENHOUSE GAS EMISSIONS FROM NATURAL GAS AND DIESEL VEHICLES

This analysis presents Air Resources Board (ARB) staff estimates of the greenhouse gas (GHG) emissions from natural gas (NG) and diesel vehicles based on the estimates of the full fuel cycle data available for NG and diesel fuel. A generalized diesel pathway was assumed that considers an overall estimate for California. The analysis covers 8 different pathways for natural gas, 5 for compressed natural gas (CNG) and 3 for liquefied natural gas (LNG), as shown below:

<u>Natural Gas Pathways to California</u>

1) NG produced in California for use as CNG fuel (*CNG-CA*).
2) NG produced in Oklahoma/Texas (Midwest) and pipelined to California for use as CNG fuel (*CNG-Midwest*).
3) NG produced in Canada and pipelined to California for use as CNG fuel (*CNG-Canada*).
4) Remote LNG shipped to Gulf Port in Texas, re-gasified into NG and pipelined to California for use as CNG fuel (*CNG-Gulf*). ‘Remote’ means that the LNG originates from foreign nations having direct, ocean-going link to the liquefaction terminal.
5) Remote LNG shipped to Baja, Mexico, re-gasified into NG, and pipelined to California for used as CNG fuel (*CNG-Baja*).
6) NG produced in Canada, pipelined to California, liquefied in the South Coast, and trucked to the ports for use as an LNG fuel (*LNG-Canada*).
7) Remote LNG shipped to Baja, Mexico, re-gasified into NG, pipelined to the South Coast, and then liquefied for use directly as a fuel for LNG vehicles (*LNG-Baja*).
8) Remote LNG shipped to the port of Long Beach and used directly as a fuel for LNG vehicles (*LNG-Pacific*).

<u>Approach</u>

Staff projected the full fuel cycle GHG emissions for light-duty vehicles (LGV) and heavy-duty vehicles (HDV) using natural gas from each of the 8 NG pathways shown above. The GHG emissions for each NG pathway were then compared to the GHG emissions from a full fuel cycle analysis of the GHG emissions for LDV and HDV using existing CARB diesel. A similar comparison was made for LDV and HDV using low carbon fuel standard (LCFS) diesel, which is diesel with 10 percent lower carbon intensity as compared to existing CARB diesel. No change in the carbon intensity of the natural gas pathways was assumed for the comparison to CARB and LCFS diesel.

<u>Conclusions</u>

Figures 1 and 2 present the results of the staff’s projections. Figure 1 shows the projected reduction in GHG emissions of using natural gas as compared to existing

CARB diesel for both LDV and HDV. Similarly, Figure 2 shows the same comparison, except with LCFS Diesel as the baseline instead of CARB diesel.

As shown in Figures 1 and 2, three general conclusions can be drawn:

(1) **CARB Diesel v. NG**: Figure 1 shows that, compared to existing CARB diesel, the use of CNG and LNG results in a **net GHG emissions benefit in nearly all 8 pathways** evaluated for both LDV and HDV. The sole exceptions to this is are: (A) for HDV using natural gas derived from the CNG-Gulf pathway, which shows a small but positive projected increase in GHG emissions relative to CARB diesel, and (B) for both LDV and HDV using natural gas derived from the LNG-Baja pathway, which show projected increases in GHG emissions relative to CARB diesel.

(2) **Delivery Distance and Increased Processing of NG have Strong Influences on GHG.** As one would expect, Figure 1 also shows that the GHG benefits from using NG decrease significantly with increased distances to deliver the gas to California and increased processing steps (particularly liquefaction). Longer shipping distances and liquefaction involves additional energy and NG losses, which increase GHG emissions; a single liquefaction is required in producing CNG from NG obtained from the Gulf and Baja pathways and LNG from the Canada and Pacific pathways, while two separate stages of liquefaction are required in the LNG-Baja pathway.

(3) **LCFS Diesel v. NG**: By contrast, Figure 2 shows a much different picture. When compared to the 10% reduced carbon intensity in LCFS diesel, **only three of the five CNG** pathways (California, Midwest, and Canada) show GHG benefits for both LDV and HDV, and **two LNG** pathways show a GHG benefit for LDV (although the LNG-Canada provides only a marginal benefit). For the remaining pathways (2 CNG and 1 LNG), staff's analysis suggests a net positive increase in GHG emissions relative to LCFS diesel for both LDV and HDV.

The attachment provides supplemental information regarding the calculational methodology and detailed information on the GHG emissions, carbon intensities (overall and by well-to-wheel segments), and assumptions made by staff.

Fig. 1 -- Reduction in GHG Emissions: CARB Diesel vs. Natural Gas

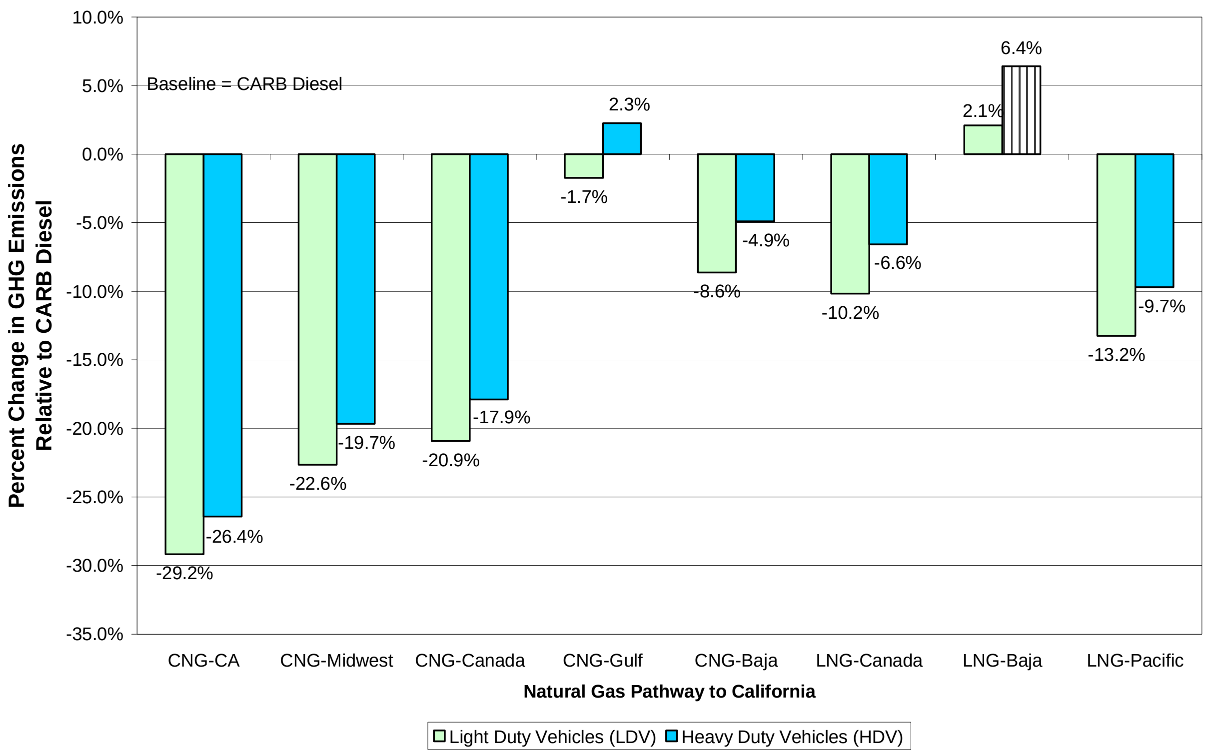
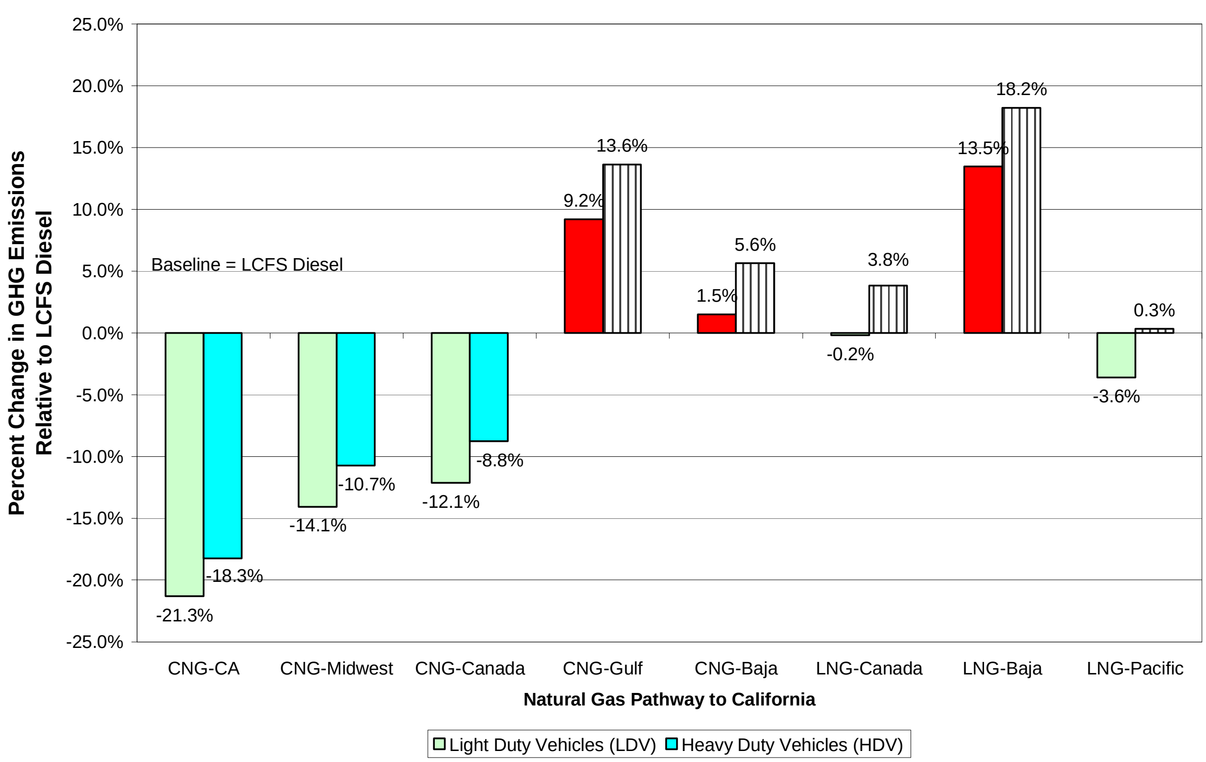


Fig. 2 -- Reduction in GHG Emissions: LCFS Diesel vs. Natural Gas



ATTACHMENT

Table 1 presents more details on staff's projections for GHG emissions for LDV and HDV using NG and diesel. The green shaded entries show those pathways for which we project a net GHG benefit from using NG relative to CARB diesel or LCFS diesel. The results are based on the data presented in Table 2. Table 3 presents additional details on the full fuel cycle assessment for the different pathways. In general, the emissions are calculated as follows:

Emissions = [Lifecycle Carbon Intensity] x [Vehicle Fuel Economy]

Emissions expressed as grams CO2 equivalent per mile
Lifecycle Carbon Intensity expressed as grams CO2 equivalent per Megajoule of Fuel
Vehicle Fuel Economy expressed as Megajoules required per mile.

Key Assumptions:

Since the April 21, 2008 release of the document entitled, "Detailed California-Modified GREET Pathway for Compressed Natural Gas (CNG) from North American Natural Gas, Version 1.0", the values for carbon intensity and fuel economy for light-duty and heavy-duty vehicles have been updated and may yet undergo further revision in the near future. As such, all the numbers presented in the accompanying tables are draft at this time. CPB is working with PTSD to obtain ARB certified tailpipe emission factors for light-duty and heavy-duty vehicles for CNG, LNG, and diesel fuels. ARB staff assigned to the LCFS project is in the process of updating all input values for the diesel pathway.

The data sets underlying the carbon intensity values for each pathway presented in Table 1 are derived from a California-specific GREET Model (created by Argonne Laboratory), version 1.8b. The fuel economy values are derived from a spreadsheet model based on the latest version of the EMFAC (ARB website), and represent an average across all categories of light-duty and heavy-duty vehicles for a particular fuel. As for the pathways, CNG and LNG can be obtained via pipeline-based natural gas or from remotely sourced LNG. ARB staff believes that the eight pathways identified in the tables represent the most likely scenarios by which CNG and LNG will be made available for use as motor vehicle fuel in California.

Conclusions

Table 1 presents a comparison of GHG emissions between existing diesel fuel and a 10% reduction in the carbon intensity of existing diesel fuel (LCFS diesel) for CNG and LNG derived from eight pathways. Table 1 suggests that in the case of light-duty vehicles, all of the CNG pathways and two of the LNG pathways present an opportunity for GHG emissions improvement, as compared to existing diesel. However, Table 1 also suggests that in the case of light duty vehicles, only three of the CNG pathways and two of the LNG pathways represent a GHG emissions improvement over LCFS diesel (although one LNG pathway shows only a very small improvement).

In the case of heavy-duty vehicles, Table 1 indicates four of the five CNG pathways and two of the LNG pathways would offer GHG emissions improvements over existing diesel fuel. In contrast, Table 1 suggests that only three of the CNG pathways and none of the LNG pathways present an opportunity for GHG emissions improvement on LCFS diesel.

ARB staff was able to generate a complete well-to-tank breakdown for each pathway, as shown in Table 3. Table 3 shows that the well-to-wheel carbon intensities for CNG and LNG pathways range from 66.3 to 96.9 grams CO2-eq/MJ for light-duty vehicles and heavy-duty vehicles, which compare favorably to the values of 96.8 and 95.9 grams CO2-eq/MJ on existing diesel fuel for light-duty and heavy-duty vehicles, respectively. However, with a ten percent reduction in carbon intensity of diesel fuel, only five of the eight pathways involving light duty vehicles and three of the eight pathways for heavy-duty vehicles produce an improvement in carbon intensity.

These results can only be considered as preliminary at the present. Values for either the carbon intensities for the various pathways or the fuel economies for light- or heavy-duty vehicles may change from those presented today. Given the currently marginal emission values of several of the pathways presented, even a small change in the supporting data sets could prove to be significant.

Table 1
Benefits in GHG Emissions of Diesel versus Natural Gas Depend on the Natural Gas Pathway to California

Fuel	Pathway	Light Duty Vehicles			Heavy Duty Vehicles		
		GHG Emissions g CO2-eq/mi	% Change[1] from: Existing Diesel	% Change[1] from: LCFS[2] Diesel	GHG Emissions g CO2-eq/mi	% Change[1] from: Existing Diesel	% Change[1] from: LCFS[2] Diesel
CNG	NG from California (CNG-Calif)	369	-29.2%	-21.3%	1781	-26.4%	-18.3%
CNG	NG from Midwest; Pipelined to California (CNG-Midwest)	403	-22.6%	-14.1%	1945	-19.7%	-10.7%
CNG	NG from Canada; Pipelined to California (CNG-Canada)	412	-20.9%	-12.1%	1988	-17.9%	-8.8%
CNG	LNG Shipped to the Gulf; NG Pipelined to California (CNG-Gulf)	512	-1.7%	+9.2%	2476	+2.3%	+13.6%
CNG	LNG Shipped to Baja; NG Pipelined to California (CNG-Mexico)	476	-8.6%	+1.5%	2302	-4.9%	+5.6%
LNG	NG from Canada; NG Pipelined to California; Liquefied for LNG Fuel Use (LNG-Canada)	468	-10.2%	-0.2%	2262	-6.6%	+3.8%
LNG	LNG Shipped to Baja; NG Pipelined to California; Liquefied for LNG Fuel Use (LNG-Mexico)	532	+2.1%	+13.5%	2576	+6.4%	+18.2%
LNG	LNG Shipped to South Coast Port and Used Directly as LNG Fuel (LNG-Pacific)	452	-13.2%	-3.6%	2186	-9.7%	+0.3%
Diesel	California Average	521	0.0%	-10.0%	2421	0.0%	-10.0%
LCFS Diesel	California Average	469	-10.0%	0.0%	2179	-10.0%	0.0%

Note: A negative percentage (-%) change means there is a projected net GHG benefit for the fuel switch.
[1] Percentages have been rounded.
[2] LCFS (Low Carbon Fuel Standard) Diesel has 10% lower carbon intensity than existing CARB Diesel.

Table 2
Carbon Intensity* and Fuel Economy Estimate Used to Determine Emissions

Vehicle Fuel	Pathway	Light Duty Vehicles		Heavy Duty Vehicles	
		Carbon Intensity g CO2-eq/MJ	Fuel Economy MJ/mile	Carbon Intensity g CO2-eq/MJ	Fuel Economy MJ/mile
CNG	NG Produced in California	67.3	5.49	66.3	26.86
CNG	NG Produced in Midwest; NG Pipelined to California	73.4	5.49	72.4	26.86
CNG	NG Produced in Canada; NG Pipelined to California	75.0	5.49	74.0	26.86
CNG	LNG Shipped to the Gulf; NG Pipelined to California	93.2	5.49	92.2	26.86
CNG	LNG Shipped to Baja; NG Pipelined to California	86.7	5.49	85.7	26.86
LNG	CNG Produced in Canada; NG Pipelined to California; Liquefied for LNG Fuel Use	85.2	5.49	84.2	26.86
LNG	LNG Shipped to Baja; NG Pipelined to California; Liquefied for LNG Fuel Use	96.9	5.49	95.9	26.86
LNG	LNG Shipped to South Coast Port and Used Directly as LNG Fuel	82.4	5.49	81.4	26.86
Diesel	California average	96.8	5.38	95.9	25.25
LCFS Diesel	California Average	87.1	5.38	86.3	25.25

*The carbon intensities were obtained from the ARB Interface Tool to Calculate the Carbon Intensity of Transportation Fuels, to be published August 14, 2008.
The EER values used to calculate fuel economies are as follows: LDV (CNG and LNG) = 0.98; HDV (CNG and LNG) = 0.94.

Table 3
Carbon Intensities by Segment for Various Fuels and Pathways

Segment	Carbon Intensity by Fuel and Pathway (g CO2-eq/MJ)								
	CNG	CNG	CNG	CNG	CNG	LNG	LNG	LNG	DIESEL
	NG Produced in California	NG Produced in Midwest; NG Pipelined to California	NG Produced in Canada; NG Pipelined to California	LNG Shipped to the Gulf; NG Pipelined to California	LNG Shipped to Baja; NG Pipelined to California	NG Produced in Canada; NG Pipelined to CA; Liquefied for LNG Fuel Use	LNG Shipped to Baja; NG Pipelined to CA; Liquefied for LNG Fuel Use	LNG Shipped to South Coast Port and Used Directly as LNG Fuel	California average
Production	3.70	3.70	3.70	3.70	3.70	3.70	3.70	3.70	6.40
Processing	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	0.0
Transport[1]	0.22	6.27	7.90	7.90	1.39	7.90	1.39	0.0	2.2
1st Liquefaction	0.0	0.0	0.0	13.0	13.0	0.0	13.0	13.0	0.0
Shipping	0.0	0.0	0.0	4.00	4.00	0.0	4.00	4.00	0.0
Regasification	0.0	0.0	0.0	1.16	1.16	0.0	1.16	0.0	0.0
Well-to-NG Pipeline Total[2]	8.12	14.17	15.8	33.96	27.45	15.8	27.45	24.9	0.0
Compression	2.9	2.9	2.9	2.9	2.9	0.0	0.0	0.0	0.0
2nd Liquefaction	0.0	0.0	0.0	0.0	0.0	11.97	11.97	0.0	0.0
LNG Truck Transport[3]	0.0	0.0	0.0	0.0	0.0	0.157	0.157	0.157	0.3
Refining	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.3
Light Duty Vehicle Combustion	56.3	56.3	56.3	56.3	56.3	57.3	57.3	57.3	75.6
Heavy Duty Vehicle Combustion	55.3	55.3	55.3	55.3	55.3	56.3	56.3	56.3	74.7
Total–Light Duty	67.3	73.4	75.0	93.2	86.7	85.2	96.9	82.4	96.8
Total–Heavy Duty	66.3	72.4	74.0	92.2	85.7	84.2	95.9	81.4	95.9
Total–Light Duty with 10% Reduction in Carbon Intensity									87.1
Total–Heavy Duty with 10% Reduction in Carbon Intensity									86.3

1. Transport includes the transmission and distribution segments.
2. The Well-to-NG Pipeline Total is the sum of the carbon intensities for the preceding segments, and are taken from a draft internal document created by Anil Prabhu (SSD) on August 12, 2008 using a California modified GREET model v1.8b (CA-GREET) .
3. LNG Truck Transport assumes a distance of 50 miles.