California Energy Commission

Clean Transportation Program

FINAL PROJECT REPORT

California Clean Fuels Compressed Natural Gas Infrastructure Upgrade Project

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PREFACE

Assembly Bill 118 (Núñez, Chapter 750, Statutes of 2007) created the Clean Transportation Program, formerly known as the Alternative and Renewable Fuel and Vehicle Technology Program. The statute authorizes the California Energy Commission (CEC) to develop and deploy alternative and renewable fuels and advanced transportation technologies to help attain the state's climate change policies. Assembly Bill 8 (Perea, Chapter 401, Statutes of 2013) reauthorizes the Clean Transportation Program through January 1, 2024, and specifies that the CEC allocate up to $20 million per year (or up to 20 percent of each fiscal year's funds) in funding for hydrogen station development until at least 100 stations are operational.

The Clean Transportation Program has an annual budget of about $100 million and provides financial support for projects that:

- Reduce California's use and dependence on petroleum transportation fuels and increase the use of alternative and renewable fuels and advanced vehicle technologies.
- Produce sustainable alternative and renewable low-carbon fuels in California.
- Expand alternative fueling infrastructure and fueling stations.
- Improve the efficiency, performance and market viability of alternative light-, medium-, and heavy-duty vehicle technologies.
- Retrofit medium- and heavy-duty on-road and nonroad vehicle fleets to alternative technologies or fuel use.
- Expand the alternative fueling infrastructure available to existing fleets, public transit, and transportation corridors.
- Establish workforce-training programs and conduct public outreach on the benefits of alternative transportation fuels and vehicle technologies.

To be eligible for funding under the Clean Transportation Program, a project must be consistent with the CEC's annual Clean Transportation Program Investment Plan Update. The CEC issued PON-12-605 to support installation of new natural gas fueling infrastructure and upgrades to existing natural gas fueling infrastructure. In response to PON-12-605, the recipient submitted an application which was proposed for funding in the CEC's notice of proposed awards March 18, 2013 and the agreement was executed as ARV-12-049 on June 30, 2013.

ABSTRACT

California Clean Fuels upgraded an existing 24-hour, 7-day per week public access compressed natural gas station with a state-of-the-art dispenser and design improvements to increase the quantity of vehicles fueled at the station.

The California Clean Fuels station is at 15330 Woodruff Avenue in Bellflower California, near the 91, 5, 605, 710 and 105 freeways, on Bellflower Unified School District property. The upgrade significantly improves California Clean Fuels' ability to serve increasing numbers of heavy-duty fleet vehicles, including school buses that travel nearby transportation corridors.

This project enhances the state's compressed natural gas fueling infrastructure network by providing a reliable source of compressed natural gas while reducing the amount of time required to fuel each vehicle. The upgraded station fuel dispensing rate estimate of more than 500,000 gasoline gallon equivalent/year within the first full year of operation was met during the project demonstration period in fall 2014 and winter 2015. The associated greenhouse gas emission reduction was roughly 2,100 metric tons (2,300 short tons) per year. The project reduces criteria pollutant emissions continually since fleets of school buses and trucks use the fuel instead of diesel. Finally, the project increases awareness of and access to compressed natural gas as a vehicle fuel.

Keywords: California Energy Commission, California Clean Fuels, compressed natural gas, CNG station, petroleum displacement, greenhouse gas, emission reduction

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EXECUTIVE SUMMARY

This project installed a new compressed natural gas dispenser and improved the station design at an existing compressed natural gas facility. Other project elements include replacing the existing 560 standard cubic feet per minute dispenser with a new Kraus Global™ 2,000 standard cubic feet per minute dispenser. This upgraded fuel dispenser eases fueling of heavy-duty vehicles at the station. Both fuel hoses dispense compressed natural gas at a maximum rate of 16 gasoline gallons equivalent per minute compared to the original rate of 4.5 gasoline gallons equivalent per minute. The new dispenser has a built-in refueling training video to ensure all new customers are trained in the safe operation of the dispenser. This project also upgraded the transformer, the electrical power distribution panel to 800 amps, and added control software upgrades to allow both compressors to operate simultaneously.

The original California Clean Fuels Compressed Natural Gas Infrastructure Upgrade Project budget was $174,543. The final project cost was $240,207 because of unexpected expenses, including the transformer upgrade and procurement price increases.

The invaluable CEC funding of $83,000 (35 percent) allowed California Clean Fuels to keep the pump price at the station competitive ($2.35 per gasoline gallon equivalent in 2014 and 2015). The CEC grant was matched by company equity of $157,207 (65 percent). The California Clean Fuels station relieves Bellflower Unified School District, MV Transportation, and RF Dickson Company, Inc. from managing the fueling station while complying with the South Coast Air Quality Management District to reduce transportation criteria pollutants.

The upgraded station dispensed 250,000 gasoline gallon equivalent during the six-month demonstration period, 500,000 gasoline gallon equivalent annual throughput. The research team estimates this throughput will reduce more than 2,100 metric tons (2,300 short tons) carbon dioxide equivalent per year compared to an average fleet of diesel-fueled school buses. Compressed natural gas-fueled vehicles also reduce criteria pollutants such as oxides of nitrogen by 34 to 97 percent and particulate matter up to 98 percent, depending on the age of the comparison vehicles.

CHAPTER 1: Purpose and Approach

This project improved California Clean Fuels' (CCF) ability to provide convenient, clean, publicly accessible compressed natural gas service for a high-growth region of Southern California. The CCF Compressed Natural Gas (CNG) Infrastructure Upgrade Project encompassed the following key elements:

- Replace the existing old CNG dispenser with a much faster dispenser that displays a training video.
- Upgrade of the electrical power distribution panel, as required by the local utility.
- Upgrade credit card transaction software at the station.

During the demonstration period of six months, nearly 250,000 gasoline gallons equivalent (GGE) were dispensed. Regular anchor fleet customers, including Bellflower Unified School District, MV Transportation and RF Dickson, Co. Inc., depended on this station for CNG fuel.

1.1 Fueling Station History

The CCF station opened in October 2002 equipped with one compressor, one dispenser, eight time-fill posts[1], and four small storage vessels. Since then, CCF expanded station capabilities, with the support of the CEC and South Coast Air Quality Management District, to include a second dispenser, a second compressor, 23 additional time-fill posts, as well as additional storage (now 12 storage vessels).

1.2 Project Goals

This project was funded to continue the existence of valuable alternative fuel infrastructure on Bellflower Unified School District property by upgrading existing CNG dispensing equipment which continues the reduction of greenhouse gas (GHG), criteria air pollutants, and air toxic emissions from the transportation system. Secondary goals include increasing volume capacity of CNG infrastructure and providing a more affordable transportation fuel source.

1.3 Project Objectives

Project objectives included:

- Dispensing about 500,000 GGE or more over 12 months based on measured station throughput at the dispensers
- Reducing greenhouse gas emissions by about 2,100 tons/year
- Reducing criteria and toxics air pollutant emissions

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[1] A time-fill occurs when a manual dispenser (a "post" with one or two hoses) is connected to a fleet vehicle (such as a school bus) overnight. Since less compressor energy and less human attention is required for this 4 to 12-hour fuel tank filling by the unattended dispenser, it is more economical over the life of the system. It costs more in the beginning, but less to operate.

- Increasing market penetration of natural gas as a transportation fuel
- Increasing awareness and accessibility of natural gas transportation fuel

1.4 Activities Performed

The station upgrade design, construction, and start-up followed well-established best practices for CNG fueling station implementation.

1.4.1 Design and Planning

CCF specified that the new dispenser design must provide high output rates and include a display with a built-in training video to show new users how to operate the dispenser safely and fuel their vehicles. This specification narrowed the decision to two manufacturers. CCF selected Kraus because it met these key requirements and has demonstrated good reliability in the field. The new Kraus Global 2,000 standard cubic feet per minute (scfm) dispenser replaced CCF's existing 560 scfm (4.5 gasoline gallons equivalent per minute (gpm)) dispenser. Each fuel hose on the new Kraus dispenser provides CNG at a maximum rate of 16 gpm. The new Kraus dispenser has a useful life of 15 years. Kraus Global dispenser specifications are in Appendix A.

As previously designed, the two compressors operated alternately. CCF upgraded the electrical power distribution panel to 800 amps, with associated control software upgrades. Though unexpected, this transformer replacement was required by the electric utility, and allows both compressors to operate simultaneously. Appendix B has more compressed natural gas transportation fuel energy facts.

The data collection plan specified tracking utility bills for the natural gas and electricity consumption of the station to determine the utilities required.

A software upgrade for credit card transactions at the station ensured seamless integration with the new dispenser. Downloads from this software deliver the operations data: number of transactions by fleet vs public, gallons of fossil fuels replaced and air emissions reductions.

CCF carefully planned the project to minimize the construction impact on station customers. No trenches or concrete were needed. The new dispenser was installed in the exact footprint of the dispenser that it replaced. The new electrical and data cables were pulled through the existing conduits for connection to the new dispenser. This approach limited the downtime of the dispenser to only four hours. The station's second dispenser was available during this time, so no customers were inconvenienced during the dispenser installation.

Since this project entailed a straightforward swap out of the dispenser, there was no opportunity to implement energy efficiency measures that exceed Title 24 standards in Part 6 of the California Code Regulations.

1.4.2 Problems Encountered and Resolved

CCF encountered two major problems during this project: manufacturing delays and electrical supply.

In the grant application CCF originally specified a promised next generation dispenser from Kraus; however, the manufacturer experienced significant delays with this new model. Waiting for this new model led to a delay of nearly a year, which led to a no-cost time extension for this agreement. After waiting, CCF, in consultation with CEC staff, ultimately decided to install the current generation design. Interestingly, that promised new design is still not commercially available, even though it was expected in late 2013. Once the alternate model was chosen, the dispenser was built and delivered in three months.

The second problem related to CCF's original upgrade design, which planned to upgrade to 800-amp service. Unfortunately, after project commencement, Southern California Edison (SCE) determined that their existing smaller transformer would not meet requirements from its placement on the power pole. A larger transformer installed on the ground was more appropriate for the station's upgraded capacity. CCF delayed the project for a few months waiting for SCE to complete the transformer upgrade. But as the SCE support was further delayed, CCF devised a project plan to proceed with the station upgrades on a parallel path to SCE's transformer upgrade. Figure 1 depicts the new transformer.

Figure 1: New Transformer, Two Views

Photo Credit: California Clean Fuels

Although the original budget was $174,543, the final project cost was $240,207 because of the unexpected transformer upgrade and other procurement increases.

1.4.3 Dispenser Capacity

The upgrade followed all applicable codes and standards. No demolition was required. Figure 2 shows the 10-year-old Greenfield Brand Dispenser that was removed. One existing 560 scfm dispenser (4.5 gpm) was replaced with a new Kraus Global 2,000 scfm dispenser. Each fuel hose dispenses CNG at a maximum rate of 16 gpm. The new dispenser includes a credit card scanner to provide the convenience of conventional fuels. Since CNG is an alternative fuel, it is a novelty to some new drivers. The built-in refueling procedures video trains all customers in the safe operation of the unique nozzle. The new Kraus dispenser is predicted to have a useful life of 15 years.

Figure 2: Vintage 2004 Greenfield Brand Dispenser, After Removal

Photo Credit: California Clean Fuels

1.4.4 Dispenser Installation and Commissioning

CCF's second dispenser operated during installation and commissioning of the new dispenser, so the station was not closed. After only four hours while one dispenser was replaced, the station upgrade was successfully operating as specified. CCF began fueling vehicles with the new dispenser on September 25, 2014. The station dispensed CNG to the school district fleet and public (that is, nonfleet) customers 24 hours per day, 7 days per week thereafter. Figure 3 shows the new equipment in place.

There were two complete station closures, each out of our control. These closures included a 10-hour shutdown on February 18, 2015, when SCE switched out the transformer, and an 8-hour shutdown on March 21, 2015, when SCE replaced its power pole. Just 18 hours of closure in 6 months is 99.6 percent up time.

Ultimately, the station was commissioned and passed Bellflower Unified School District's inspection.

Figure 3: New Kraus Dispenser, With Video Training Loop

Photo Credit: California Clean Fuels

CCF began a six-month demonstration period, downloading operations data from the dispenser software. The data collection plan also required tracking utility bills for the natural gas and electricity consumption of the station.

The station operated for six-months while data were collected in accordance with the CEC grant agreement terms. Results of this data collection are documented in Chapter 2 below. During the project, CCF completed the administrative tasks including project meeting participation, submittal of milestone reports, and on-time submission of monthly project reports.

CHAPTER 2: Project Results

Chapter 2 discusses station operation metrics and project results.

Two efforts coordinated with suppliers delayed the schedule. The local utility's unexpected requirements added months to the project. The possibility of purchasing a dispenser with better features convinced us to wait for the vendor's engineering developments. All other aspects of the project were completed on time.

2.1 Customer Loss

During the project one of CCF's major customers, Norwalk Transit, built its own CNG fueling station with Clean Energy Fuels Corp. In addition, another major CCF fleet customer, City of Commerce's transit fleet, recently began fueling at its new Clean Energy Fuels Corp. station. This addition of stations in the CCF operating area has diluted CCF's customer base, causing a significant drop in throughput that CCF did not anticipate in the proposal, or at the beginning of the project. To offset this loss, CCF is working with existing and new customers to recover, and then grow, station throughput.

2.1.1 Energy Consumption

The daily average fuel dispensed was 1,360 GGE, about 1800 therms/day. Electrical energy is consumed by two compressors to deliver the natural gas fuel to the vehicles. Table 1 below lists the average daily energy consumption during each month at the CCF station, an average of 1,270 kilowatt-hour (kWh)/day. Roughly, one gasoline gallon equivalent was dispensed per kWh electrical energy consumed. This can be restated as approximately 1.4 therms per kWh electrical energy consumed.

There were no current or future vehicle acquisitions required as part of this grant. The expected duty cycle of vehicles fueling at the station is unknown. Light duty, medium duty and heavy-duty vehicle types got fuel at the station include school buses, transit buses, waste-hauling trucks, street sweepers, and miscellaneous passenger cars. CCF intends to continue to expand its customer base. It is likely that the distribution of future vehicles will be a mix similar to the current customer fleet mix.

Table 1: Energy Consumption and CNG GGE Throughput (Daily Average)

Month	Therms/Day	kWh/Day	GGE/Day
October 2014	2,452	1,542	1,782
November 2014	1,844	1,384	1,589
December 2014	1,620	1,248	1,254
January 2015	1,575	1,025	1,038
February 2015	1,355	1,093	1,162
March 2015	2,011	1,349	1,354
Average over 6 Months	**1,800**	**1,270**	**1,360**

Source: California Clean Fuels Operating Data

An average of 40,000 GGE/month was dispensed during the six-month demonstration (shown below in Table 2). The maximum was 57,257 GGE dispensed in October 2014, before the customer loss.

Table 2: Throughput in GGE per Month

Month	**Monthly Gasoline Gallon Equivalent (GGE/month)**	**Estimated Mileage per Month**[2]
September 2014	9,597	69,050
October 2014	57,257	411,995
November 2014	42,617	306,652
December 2014	38,438	276,582
January 2015	34,468	248,016
February 2015	31,622	227,537
March 2015	34,365	247,275
Total:	**248,364 GGE**	**1,718,057 miles**

Source: Based on California Clean Fuels Operating Data or estimated as noted.

Detailed mileage information for vehicles that fuel at the CCF station is not available. The station does not have a mechanism to track the vehicle class or mileage accumulation of each vehicle.

Fuel sales are collected in one large daily fuel fleet purchase, which could cover any number of vehicles from a single fleet, but the amount of fuel by vehicle is not collectable with the current system.

During the 6-month demonstration period, there were two station shutdowns, totaling 18 hours:

- 10 hours for SCE to upgrade the transformer
- 8 hours for SCE to replace their power pole

Upgrading the transformer was part of installation of new equipment. Replacing the power pole had nothing to do with this project. But SCE noticed when working on the transformer upgrade that the power pole change-out was long overdue and scheduled it for prompt attention. Just 18 hours of closure in six-months is 99.6 percent up time. During normal operations there were no inoperative hours.

[2] This estimate is based on results from a run of the California Air Resources Board's Emissions Factor model for on-road vehicles, EMFAC 2011, with the assumption that all vehicles fueling at the station were fleet-average school buses. From EMFAC, the average fuel consumption for a diesel-fueled school bus is 7.2 miles per gallon. CCF took this approach because the data are not available to indicate the vehicle type for each fuel transaction.

2.2 Throughput, Usage, and Operations Data Collected

Upon commissioning the newly upgraded dispenser, CCF began a six-month demonstration period, downloading operations data from the dispenser software. The utility bills for the natural gas and electricity consumption of the station were collected.

Kraus Global's stated maximum flow rate of 2000 scfm reflects the rate at which the internal piping system of the dispenser is capable of flowing compressed natural gas into the inlet of the nozzle at maximum pressure differential. Flow rate decreases as the tank gets full. The actual flow rate into the vehicle system may be limited by the nozzle selection and the internal vehicle piping configuration. The fueling station is theoretically able to do 360 fills/day, assuming 2 hoses, 4 minutes to fill the tank after 4 minutes to pull up to the pump and pay.

2.2.1 Throughput 248,364 GGE in Six Months

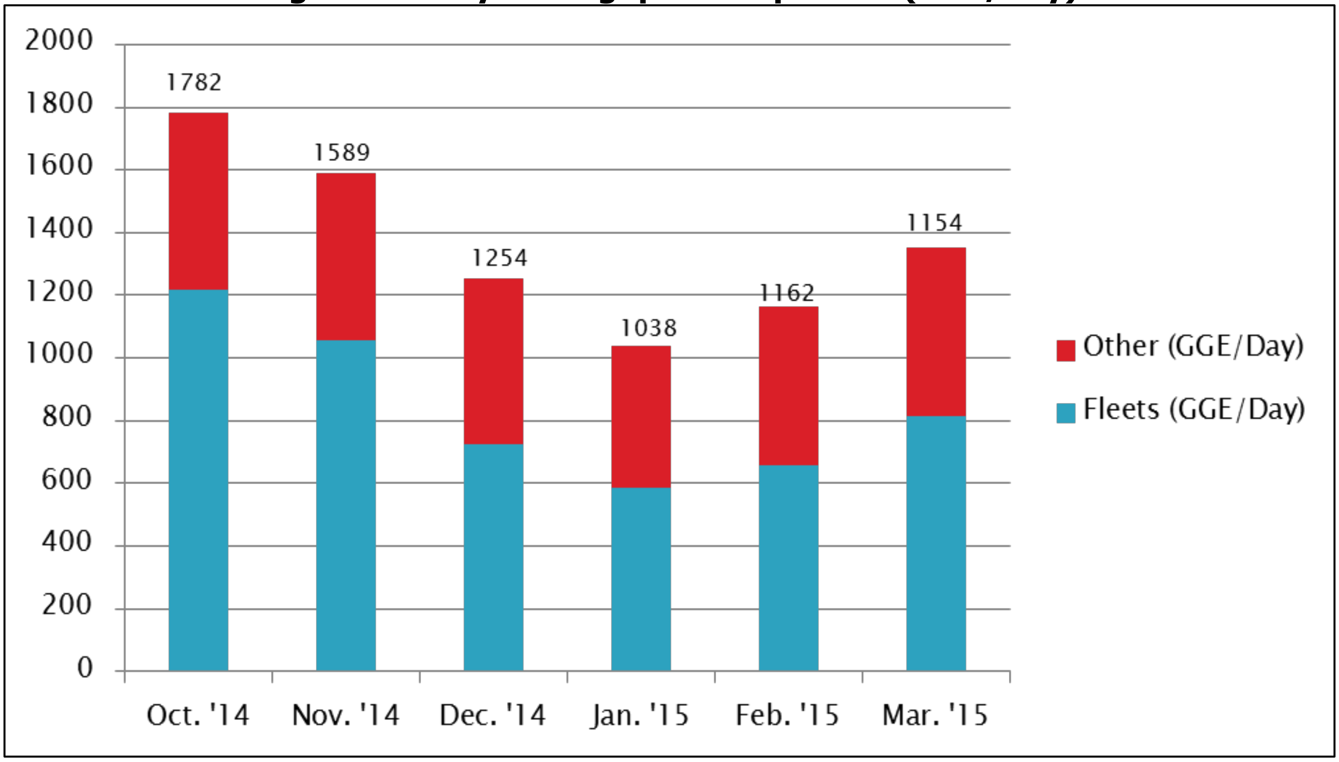
The actual measured throughput during data collection period was 248,364 GGE. At this rate, the annual throughput is projected at nearly 500,000 GGE/year.

During this demonstration period, which ran from September 25, 2014 through March 25, 2015, the station logged:

- Nonfleet customer (public, miscellaneous credit card transactions):
    - More than 7,000 transactions, or 39 transactions per day, on average.
    - A total of 94,600 GGE dispensed, or 520 GGE dispensed per day, on average.
- Fleet customers:
    - Fleet vehicle throughput represents 62 percent of total station throughput.
    - A minimum of 641 times at least one fleet vehicle fueled at the station. The actual number of vehicles was greater than this number. A count of fleet vehicles fueled cannot be reported because the fleets do not have fueling cards for each vehicle. (All fueling events are from same card).
    - 153,636 GGE dispensed in total, or 844 GGE dispensed per day, on average.
    - Bellflower Unified School District has 31 time-fill posts supplied by CCF. The usage varies depending on Bellflower Unified School District fleet operations. The school bus consumption is reported within the fleet usage.

See Figure 4 for a comparison of fleet and nonfleet usage, on average, in units of GGE per day.

Figure 4: Daily Throughput Comparison (GGE/Day)



Source: California Clean Fuels Operating Data

2.3 Greenhouse Gas Emission Reductions

During the six-month data collection period, an estimated **1,052 metric tons of carbon dioxide equivalent (CO2e)** (1,160 short tons CO2e) of emissions were avoided by customers of California Clean Fuels, almost exactly CCF's goal. The exact mix of vehicle customers at the station is not available, so these GHG benefits were estimate based on the actual therms of natural gas consumed (dispensed) by the station and assuming the Bellflower group of school buses the station serves now as a sample fleet.

Another way to document the GHG reduction benefits of natural gas as a transportation fuel is to compare its carbon intensity[3] (CI) to baseline fuels. According to the California Air Resources Board (ARB) 2009 Low Carbon Fuel Standard (LCFS) regulation, the CI of CNG is 68.00 grams of carbon dioxide per megajoule[4] (gCO2e/MJ). This compares with 98.03

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[3] Carbon Intensity is the amount of carbon by weight emitted per unit of energy consumed. United States Environmental Protection Agency Website (https://www.epa.gov/greenpower). Accessed June 18, 2015.

Further sources: Air Resources Board LCFS carbon intensity look-up tables (http://www.arb.ca.gov/fuels/lcfs/lu_tables_11282012.pdf) on and LCFS Final Regulation Order (http://www.arb.ca.gov/fuels/lcfs/CleanFinalRegOrder112612.pdf) item CNG002 from 2009.

[4] One megajoule is a million joules. The joule is a derived unit of energy, work, or amount of heat in the International System of Units (SI). It is equal to the energy transferred when applying a force of one newton through a distance of one meter (1 newton meter), or in passing an electric current of one ampere through a resistance of one ohm for one second.

gCO2e/MJ for diesel fuel and 98.38 gCO2e/MJ for gasoline. In the current case, the CI of CNG is about 30 percent, and 30.03 gCO2e/MJ, less than diesel.

The California ARB is revising and readopting the LCFS regulation during 2015, including recalculated CI for many transportation fuels. The proposed changes as of June 4, 2015[5] are shown below:

- The Cl for diesel changed from 102.82 to 102.01
- The Cl for California Reformulated Gasoline (CaRFG) changed from 99.18 to 98.47
- The Cl for CNG[6] changed from 81.63 to 78.37

Even with ARB's proposed revision to its transportation fuels CI values, CNG would still be estimated to provide nearly 21 percent GHG reduction benefit.

A method to further reduce the greenhouse gas emissions of natural gas fuel is to procure natural gas that is derived from renewable feedstock, i.e. biogas from an anaerobic digester, or biomethane from a landfill. During the period leading up to CCF's application, CCF contacted two renewable natural gas suppliers to investigate arrangements to increase its renewable feedstock ratio. CCF was informed that all of the available renewable natural gas from these vendors had already been committed to clean energy and was not available. CCF is very interested in pursuing the concept of supplementing its natural gas supply with renewable feedstock and welcomes assistance from CEC staff. Also, Southern California Gas Company is looking into renewable feedstock. Since CCF receives its natural gas from this utility, any CI changes, including enhancements based on increased use of renewable feedstock, will affect the transportation fuel CI value at this station.

Another view is that since the station is stationary, no fuel is consumed, and no transportation greenhouse gas has been prevented directly. Yet, without fueling infrastructure, the vehicles the station serves would not be on the road.

2.4 Criteria and Toxic Air Pollutant Emission Reductions

The United States Environmental Protection Agency (EPA) describes the air quality in a given area by quantifying six common air pollutants known as criteria pollutants[7]. One of these pollutants, lead, is still an issue in Southern California[8], but is no longer transportation

[5] California ARB Proposed Re-Adoption of the Low Carbon Fuel Standard (http://www.arb.ca.gov/regact/2015/lcfs2015/lcfssignednotice.pdf). Accessed August 4, 2015. P 3. #6

[6] Table 7 Temporary Fuel Pathway (http://www.arb.ca.gov/regact/2015/lcfs2015/lcfs2015.htm) (for Fossil CNG before EER considerations) pages 8, 52 Accessed August 4, 2015.

[7] United States Environmental Protection Agency Criteria Air Pollutants. (https://www.epa.gov/criteria-air-pollutants) 2/02/2016

[8] SCAQMD. 2012 Lead State Implementation Plan (SIP) Los Angeles County (https://www.aqmd.gov/home/air-quality/clean-air-plans/lead-state-implementation-plan)

caused[9]. Among the other criteria pollutants, ground level ozone is not emitted directly into the air but is created by chemical reactions between oxides of nitrogen (NOx) and volatile organic compounds (VOC) in the presence of sunlight[10]. VOC minus NOx approximates non-methane hydrocarbons according to Appendix C definitions. These pollutants are part of Exhaust Emission Standards[11] Title 13, California Code of Regulations, (13 CCR) Section 2423.

Comparing transformation from diesel fueled to natural gas fueled vehicles, PM10, PM2.5 and sulfur oxides decreased while the total VOC, CO and NOx increased (see Appendix D). How the Appendix D criteria pollutant quantities were determined from the 2015 update of the California Greenhouse Gases, Regulated Emissions, and Energy Use in Tranbsportation2.0 T1 model is shown in Appendix E.

2.4.1 New CNG Vehicle Emissions per NGV America

New CNG vehicle emissions were less than those from existing gasoline-powered and diesel vehicles *in every class*. The light-duty CNG-fueled Honda Civic emits[12] half the NO_x, 80 percent less nonmethane hydrocarbon (NMHC) and 60 percent less carbon monoxide (CO) than the gasoline version. When compared to new CNG-fueled medium- and heavy-duty trucks and buses, the natural gas fueled vehicles reduce NO_x by more than 90 percent and particulate matter (PM_{10}) by 98 percent, compared to in-use diesel fueled versions. All natural gas vehicles (NGVs) fueling at the CCF station provide well-established environmental benefits, as evidenced by the South Coast Air Quality Management District's fleet rules, which require the use of clean fuels in a variety of fleet applications. Table 3 shows the percentage emissions reductions.

Table 3: Percentage Emissions Reduction of New NGVs Compared to In-Use Gasoline and Diesel Vehicles

	CNG v. Gasoline				**CNG v. Diesel**		**CNG v. Diesel**	
	Passenger Car		**Light-Duty Truck**		**School Bus**		**Heavy-Duty Truck**	
	2002	**2007**	**2002**	**2007**	**2002**	**2007**	**2002**	**2007**
GHG	18	18	25	25	25	25	25	25
NOx	91	34	97	91	92	76	95	88
PM10	50	0	98	12	98	21	98	22

Source: NGV America, https://www.ngvamerica.org/environment/ Accessed 4/22/15.

[9] United States Environmental Protection Agency Air Quality Designs for Lead. (https://www.epa.gov/lead-designations)

[10] United States Environmental Protection Agency, Ground-Level Ozone Pollution (https://www.epa.gov/ground-level-ozone-pollution) 2/02/2016.

[11] Division 3. Air Resources Board. Chapter 9. Off-Road Vehicles and Engines Pollution Control Devices Article 4. Heavy-Duty Off-Road Diesel Cycle Engines § 2423. Exhaust Emission Standards and Test Procedures--Heavy-Duty Off-Road Diesel Cycle Engines. (b)(1) Table 1. - Exhaust Emission Standards (grams per kilowatt-hour)

[12] United States Department of Energy, CNG Honda Civic Fact Sheet, https://afdc.energy.gov/files/pdfs/civic.pdf accessed 4/22/15

"It is not expected that fuel alone makes a major impact on emissions because CNG fuel specification in California has not been changed since its establishment in 1991."[13]

2.4.2 Formaldehyde Emissions

Recent vintage trucks using the station during the demonstration period were designed to meet California emissions regulations including up to 40 milligram/mile formaldehyde emissions. In the near future, 2016 and beyond trucks will be designed to emit up to 6 mg/mile formaldehyde emissions maximum (see Appendix F) by government regulation.

2.5 Ancillary Project Benefits

As described above, this project involved a straightforward replacement of an existing CNG fueling station dispenser, along with some utility work to provide safe and sufficient power. No new jobs were created for this project, though work was conducted by experts already trained for the tasks. This state grant spending preserved those high-tech jobs. The project supported the ongoing viability of CNG as a transportation fuel by purchasing specialty equipment that required installation expertise.

The state sales taxes paid on the project equipment benefit the general fund.

State sales tax revenues could be slightly less in 2015 than 2014 due to CCF's loss of fleet customers. Yet the South Coast Air Basin is desperately in need of cleaner vehicles that use compressed natural gas. As South Coast Air Quality Management District presses companies to clean the air, CNG sales at the station will increase, and additional state sales tax revenues will result.

The project enhances California's energy independence by reducing petroleum-based transportation fuel consumption.

If California Clean Fuels had paid the full cost of this station upgrade, the payback[14] would have been 15 years. A simple payback of 10 years will be achieved as a result of the invaluable CEC funding of $83,000 (35 percent). It allowed CCF to keep the pump price at the station competitive ($2.35 per GGE in 2014 and 2015). The CEC grant was matched by company equity of $157,207 (65 percent).

Alternative fuels funding is very valuable to the community. The California Clean Fuels station relieves individuals and fleets, including Bellflower Unified School District, MV Transportation, and RF Dickson Company, Inc., from managing fueling stations to comply with the South Coast Air Quality Management District to reduce transportation criteria pollutants.

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[13] Seungju Yoon , John Collins , Arvind Thiruvengadam , Mridul Gautam , Jorn Herner & Alberto Ayala (2013) Criteria pollutant and greenhouse gas emissions from CNG transit buses equipped with three-way catalysts compared to lean-burn engines and oxidation catalyst technologies, Journal of the Air & Waste Management Association, 63:8, 926-933,DOI:10.1080/10962247.2013.800170. Downloaded 10/11/15 (http://dx.doi.org/10.1080/10962247.2013.800170)

[14] Payback considers the initial investment costs and the resulting annual cash flow. The payback period is the amount of time (usually measured in years) to recover the initial investment in an opportunity. Pacific Northwest Pollution Prevention Resource Center https://pprc.org/ (Accessed August 5, 2015).

CHAPTER 3: Conclusions and Recommendations

3.1 Achievement of Goals and Objectives

The CCF CNG Infrastructure Upgrade Project almost quadrupled the station dispensing speed by replacing the existing 560 scfm dispenser with a 2,000 scfm dispenser. Stated another way, since the two hoses at 4.5 gpm were replaced by two 16 gpm hoses on the new fuel dispenser, customers leave the station 4 times faster.

Although the public is familiar with dispensing liquid fuels to the ubiquitous gasoline-fueled family car, a gaseous fuel is still a novelty to many people. The built-in fueling training video on the face of the new dispenser reminds all customers how to safely operate the dispenser.

The station upgrade reduced toxic criteria air pollutants as well as greenhouse gas emissions. NGV are documented to operate with reduced emissions compared to conventionally fueled vehicles. This project increased the capacity of the Southern California Air Quality Management District's CNG infrastructure. Since more fuel can be dispensed per minute, more vehicles can cycle through the station each day.

Another benefit that CNG customers experience is stable fuel prices, a great advantage for NGV operators, especially in times of high petroleum-based fuel costs. Yet CCF did not see any change in activity at the station in recent months when gasoline prices plummeted. Regular anchor fleet customers that include Bellflower Unified School District, MV Transportation and R F Dickson, Co. Inc., depended on this station for CNG fuel. The spring 2015 price has been stable around $2.35/GGE, so even a price as low as $2.80 per gallon of gasoline is not a threat to CCF's NGV market share. Because natural gas is a domestic product, increased use of natural gas as a transportation fuel enhances California's and the nation's energy security, an additional benefit.

3.2 Results Obtained

The successful design, construction, and reliable operation of the CCF CNG station upgrade demonstrated the excellent work of a terrific project team. More than 7,000 transactions were completed for vehicles operated by the public during its first six months of operation, in addition to daily use by CCF's fleet partners including the Bellflower Unified School District night-time fueling.

The ability to remain on schedule was primarily hindered by unexpected requirements from the local utility, but all other aspects of the project were completed as planned and on time due to competent project planning and this team's thorough understanding of the project scope. This type of coordinated effort is critical to ensure success in similar CNG station upgrade projects.

Key results are summarized below:

- 248,364 GGE displaced during the six-month demonstration period. Projecting to an annual basis, it is expected that station throughput will reach 500,000 during the first year of dispenser operation.

- 1,052 metric tons (1,160 short tons) of Co2e reduced during the six-month demonstration period.
- 2,100 metric tons (2,300 short tons) CO_2e/year of greenhouse gases reduced.
- Significant reduction in criteria pollutants and toxic particulate matter.
- California's foreign energy independence is increased by reducing petroleum-based transportation fuel consumption.

CCF appreciates the CEC's support, especially the agreement manager, Miki Crowell, who was a terrific asset to the team.

CCF is pleased with the results of this project. The success of this project could not have been achieved without CCF's committed project team and customer cooperation.

3.3 Recommendations

CCF recommends that future natural gas vehicle fuel infrastructure upgrade projects include sufficient planning time to coordinate with the local utility, approximately 8 months, to avoid the need for time extensions in future agreements.

GLOSSARY

CALIFORNIA AIR RESOURCES BOARD (ARB)—The "clean air agency" in the government of California whose main goals include attaining and maintaining healthy air quality, protecting the public from exposure to toxic air contaminants, and providing innovative approaches for complying with air pollution rules and regulations.

CALIFORNIA CODE OF REGULATIONS (CCR)—The official compilation and publication of the regulations adopted, amended, or repealed by state agencies pursuant to the Administrative Procedure Act (APA). Properly adopted regulations that have been filed with the Secretary of State have the force of law. The CCR is compiled into Titles and organized into Divisions containing the regulations of state agencies.14

CALIFORNIA ENERGY COMMISSION (CEC)—The state agency established by the Warren-Alquist State Energy Resources Conservation and Development Act in 1974 (Public Resources Code, Sections 25000 et seq.) responsible for energy policy. The CEC's five major areas of responsibilities are:

1. Forecasting future statewide energy needs.
2. Licensing power plants sufficient to meet those needs.
3. Promoting energy conservation and efficiency measures.
4. Developing renewable and alternative energy resources, including providing assistance to develop clean transportation fuels.
5. Planning for and directing state response to energy emergencies.

Funding for the CEC's activities comes from the Energy Resources Program Account, Federal Petroleum Violation Escrow Account, and other sources.

CARBON DIOXIDE EQUIVALENT (CO2e)—A metric used to compare emissions of various greenhouse gases. It is the mass of carbon dioxide that would produce the same estimated radiative forcing as a given mass of another greenhouse gas. Carbon dioxide equivalents are computed by multiplying the mass of the gas emitted by its global warming potential.

CARBON MONOXIDE (CO)—A colorless, odorless, highly poisonous gas made up of carbon and oxygen molecules formed by the incomplete combustion of carbon or carbonaceous material, including gasoline. It is a major air pollutant on the basis of weight.

CARBON INTENSITY (CI)—The amount of carbon by weight emitted per unit of energy consumed. A common measure of carbon intensity is weight of carbon per British thermal unit (Btu) of energy. When there is only one fossil fuel under consideration, the carbon intensity and the emissions coefficient are identical. When there are several fuels, carbon intensity is based on their combined emissions coefficients weighted by their energy consumption levels.

COMPRESSED NATURAL GAS (CNG)—Natural gas that has been compressed under high pressure, typically between 2,000 and 3,600 pounds per square inch, held in a container. The gas expands when released for use as a fuel.

GASOLINE GALLON EQUIVALENT (GGE)—The amount of alternative fuel it takes to equal the energy content of one liquid gallon of gasoline. GGE allows consumers to compare the energy content of competing fuels against a commonly known fuel—
gasoline. GGE also compares gasoline to fuels sold as a gas (natural gas, propane, and hydrogen) and electricity.

GREENHOUSE GAS (GHG)—Any gas that absorbs infrared radiation in the atmosphere. Greenhouse gases include water vapor, carbon dioxide (CO2), methane (CH4), nitrous oxide (NOx), halogenated fluorocarbons (HCFCs), ozone (O3), perfluorinated carbons (PFCs), and hydrofluorocarbons (HFCs).

KILOWATT-HOUR (kWh)—The most commonly used unit of measure telling the amount of electricity consumed over time, means one kilowatt of electricity supplied for one hour. In 1989, a typical California household consumed 534 kWh in an average month.

LOW-EMISSION VEHCILE PROGRAM (LEV)—Program requiring automobile manufacturers to introduce progressively cleaner light- and medium-duty vehicles with more durable emission controls from the 1994 through 2003 model years.[15]

MEGAJOULE (MJ)—A joule is a unit of work or energy equal to the amount of work done when the point of application of force of one newton is displaced one meter in the direction of the force. It takes 1,055 joules to equal a British thermal unit. It takes about one million joules to make a pot of coffee. A megajoule itself totals one million joules.

NATURAL GAS VEHICLE (NGV)—An alternative fuel vehicle that uses compressed natural gas (CNG) or liquefied natural gas (LNG).

NITROGEN OXIDES (OXIDES OF NITROGEN, NOx)—A general term pertaining to compounds of nitric oxide (NO), nitrogen dioxide (NO2), and other oxides of nitrogen. Nitrogen oxides are typically created during combustion processes and are major contributors to smog formation and acid deposition. NO2 is a criteria air pollutant and may result in numerous adverse health effects.

PARTICULATE MATTER (PM)—Unburned fuel particles that form smoke or soot and stick to lung tissue when inhaled. A chief component of exhaust emissions from heavy-duty diesel engines.

RENEWABLE NATURAL GAS (RNG)—Or biomethane, is a pipeline-quality gas that is fully interchangeable with conventional gas and thus can be used in natural gas vehicles. RNG is essentially biogas (the gaseous product of the decomposition of organic matter) that has been processed to purity standards. Like conventional natural gas, RNG can be used as a transportation fuel in the form of compressed natural gas (CNG) or liquefied natural gas (LNG).

SOUTHERN CALIFORNIA EDISON (SCE)—One of the nation’s largest electric utilities, which delivers power to 15 million people in 50,000 square miles across central, coastal, and Southern California, excluding the City of Los Angeles and some other cities.

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[15] CARB Low-Emission Vehicle Program About webpage. https://ww2.arb.ca.gov/our-work/programs/low-emission-vehicle-program/about.

STANDARD CUBIC FEET PER MINUTE (SCFM)—The molar flow rate of a gas corrected to standardized conditions of temperature and pressure, thus representing a fixed number of moles of gas regardless of composition and actual flow conditions.

VOLATILE ORGANIC COMPOUNDS (VOCs)—Carbon-containing compounds that evaporate into the air (with a few exceptions). VOCs contribute to the formation of smog and/or may themselves be toxic. VOCs often have an odor and some examples include gasoline, alcohol and the solvents used in paints.

APPENDIX A: Kraus Global Dispenser

Figure A-1 shows the introduction information for the Kraus Global Dispenser.

Figure A-1: Kraus Global Dispenser Introduction

Kraus GLOBAL
Transportation Refueling Products

Customer Name:	American Clean Fuels
Contact Name:	Steve Dickson
Project:	CNG Dispensers
Account Manager:	Dev Patel
Quote Number:	K2393 R00
Date:	May 30th, 2014
Quote Expiry:	July 30th, 2014

Introduction

Kraus Global is a leading provider of alternative fuels dispensers for the global transportation market. Kraus has engineered and developed innovations, such as easy-to-use, LPG, CNG, LNG and Hydrogen dispensing systems, electronic registers, and automatic temperature compensation systems that have helped shape the industry.

Kraus is focused on the design and manufacturing of world-class dispensers, components and electronics for alternative fuels. Because of our history of designing and packaging reciprocating compressors, priority sequencing panels and the development of complete CNG stations, Kraus Global's dispenser designs are based on a thorough understanding of a CNG station.

More than 5000 Kraus dispensers are now installed in over 30 countries around the world. This global experience allows Kraus to be familiar with the varied customer requirements in each market.

To support this rapidly growing global market, Kraus has 44,000 square feet of dedicated production space and test facilities capable of full load testing of all dispensing equipment on natural gas or LPG at operating conditions. This ISO 9001:2000 registered facility is capable of producing 4000+ dispensers per year.

Collaborating with a worldwide network of proven component suppliers Kraus dispensers are recognized for their quality and performance. These suppliers are experts in their own field and bring new technology and advancements to their CNG components that are greater than any one company with limited resources can sustain. Kraus is able to leverage the production capacity of this global supply chain to spread the workload, minimize delivery times and add flexibility when demand suddenly increases due to tender awards or significant market growth. Should the need arise; our key component suppliers have a worldwide sales and service network which is available for field support. Finally, Kraus is able to leverage foreign currency advantages within the market by sourcing a smaller or larger percentage of supply through various countries to ensure competitive pricing.

Kraus Global offers the benefit of our experience and knowledge in the following quotation for equipment. It has been custom designed to suit your application, and was prepared with the skill and precision of our dedicated staff members. This quotation outlines the scope of work to be provided by Kraus Global for the proposed project and associated technical specifications.

1.0 Scope of Supply

In response to your request, Kraus Global Inc. is pleased to present the following equipment quotation to suit your application:

KRAUS MODEL NUMBER	DESCRIPTION	QUANTITY OFFERED
DAM 3CGG-P62CY11S1S01 *Dual hose, Light Duty*	2000 SCFM, dual hose, three line, CNG dispenser housed within a Gilbarco cabinet with color CRIND. This dispenser includes standard holsters, 3600 psi filling pressure, and OPW CT1000 nozzles. The KAF402 series solenoid valves will be utilized for fill control.	1

All Kraus equipment fully complies with the following specifications:

CNG Codes	NFPA 52 Compressed Natural Gas Vehicular Fuel Systems Code
Electrical Code	NFPA 70 National Electric Code
Piping Code	ASME B31.3 – Piping Code

A note on posted Kraus Global dispenser flow rates:

Kraus Global's stated flow rates reflect the rate at which the internal piping system of the dispenser is capable of flowing compressed natural gas into the inlet of the nozzle at maximum pressure differential assuming full flow is available at the dispenser inlet. The actual flow rate into the vehicle system may be limited by the nozzle selection and the internal vehicle piping configuration.

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2.0 Technical Specifications

2.1 Model: DAM 3CGG-P62CY11S1S01 – Dual Hose, Light Duty

CNG Dispenser

Dual hose, three line, high style CNG dispenser in a Gilbarco retail cabinet. The dispenser is designed for a 2000 SCFM flow rate. Control via KAF 402 series solenoid valves. Delivery pressure set to 3600 psi.

Dispenser Control	Internal flow-rate based sequencing control via Micon 500C computerized register unit
Number of Inlet Lines	Three
Flow Meters	Micro Motion CNG050
Flow Capacity Rating	**Hose 1:** 2000 SCFM **Hose 2:** 2000 SCFM
Flow/Sequencing Control	**Hose 1:** Kraus KAF 402 pilot solenoid valve **Hose 2:** Kraus KAF 402 pilot solenoid valve
Dispenser Filters	One per inlet, installed in dispenser
Temperature Compensation	Kraus PFS 3600 electronic temperature compensation, set to: 3 600 psig @ 70 °F
Dispensing System Accuracy	± 1%
Pressure Rating	5 000 psig MAWP
Temperature Rating	-20 deg C to +60 deg C
Required Electrical Supply	120 VAC, 60 Hz
Electrical Rating	Class I, Division I, Group D hazardous locations w/ fully internal meter electronics
Cabinet	Gilbarco Encore 700S with CRIND, Color Display (10.4"), SS lower front doors, and single tone bezel. Unit is EMV compliance ready
Breakaway	**Hose 1:** Main Line: Staubli BRW08 Vent Line: Staubli BRW02 **Hose 2:** Main Line: Staubli BRW08 Vent Line: Staubli BRW02
Hose	**Hose 1:** Parker ½" main line – ¼" vent line, 12 ft OAL, electrically conductive (no hose retractors) **Hose 2:** Parker ½" main line – ¼" vent line, 12 ft OAL, electrically conductive (no hose retractors)
Nozzles	**Hose 1:** OPW CT1000 **Hose 2:** OPW CT1000
Venting	Captive venting for return to dispenser located at the bottom of the dispenser
Tubing	**Hose 1**: All process tubing ½" SS w/ double ferrule compression fittings **Hose 2**: All process tubing ½" SS w/ double ferrule compression fittings
Fill Pressure	**Hose 1:** 3600 psig compensated fill **Hose 2:** 3600 psig compensated fill
Pressure Relief Valves	ASME certified valves to be provided; one per hose
Holster Location	One on each front side of dispenser
Approvals/Compliance	UL/CSA (components only), NFPA 52, NFPA70, ASME B31.3, NTEP W&M
Extras	• One external manual shutoff valve installed per hose • Inlet valves not included • ESD not included • Purge fan assembly included in cost

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Source: Kraus Global

APPENDIX B: LCFS Definitions and Terms

The Regulatory Advisory 14-01 (Figure B-1) from the Low Carbon Fuel Standard has both definitions of terms and constants to be used for conversion of compressed natural gas from pounds to standard cubic feet.

Figure B-1: LCFS Regulatory Advisory 14-01

Regulatory Advisory

February 2014

Low Carbon Fuel Standard Regulatory Advisory 14-01

Conversion of Compressed Natural Gas From Pounds to Standard Cubic Feet For Purposes of Reporting Compressed Natural Gas Transactions Under The California Low Carbon Fuel Standard

BACKGROUND AND SCOPE

Regulated parties selling compressed natural gas (CNG) as transportation fuel in California must report their transactions under the California Low Carbon Fuel Standard (LCFS) in units of standard cubic feet (scf) (California Code Regulations, title 17, §95484 (b)(3)(B)1). This Advisory provides specific guidance to CNG providers on how to calculate scf for purposes of complying with the LCFS reporting requirements.

All fuel transactions must be reported quarterly and annually ((California Code of Regulations, Title 17, §95484 (b)(3)). Quarterly and annual transactions reports are entered into or uploaded to the LCFS Reporting Tool (LRT). The LRT then calculates the credits or deficits associated with the reported fuel volumes using the formula specified in the regulation at California Code of Regulations, title 17, §95485(a)(3). In the case of CNG, that formula is as follows:

$$\left(Baseline\ CI - \left(\frac{Pathway\ CI}{EER}\right)\right) \times (Reported\ scf\ \times Energy\ Density\ \times EER) \times 0.000001$$

Where:

"Baseline (CI)" is either the gasoline or diesel baseline carbon intensity, depending upon the type of fuel being reported. The 2014 baseline CIs are 97.47 and 96.56 gCO_2e/MJ for gasoline and diesel, respectively (Tables 1 and 2, California Code of Regulations, title 17, §95482(b)).

"Pathway CI" is the carbon intensity of the fuel that is being reported (California Code of Regulations, Title 17, §95486). CI values are denominated in units of grams of CO2-equivalent emissions per megajoule of fuel energy produced (gCO_2e/MJ).

"EER" is the fuel's energy-economy ratio. The EER is a unitless factor used to adjust CI values to reflect the relative efficiency of the vehicle's drive train. EERs are found at California Code of Regulations, title 17, §95485(a)(3)(B) and (C).

"Reported scf" is the volume of fuel reported in the fuel transaction.

"Energy Density" is the amount of energy (in megajoules) contained in each unit of fuel (Table 4, California Code of Regulations, title 17, §95485(a)(1)).

0.000001 is the factor that converts greenhouse gas emissions expressed in units of gCO_2e/MJ into units of metric tons of carbon dioxide equivalent greenhouse gases (CO_2e). LCFS Credits and deficits are denominated in units of metric tons of CO_2e.

Table 4 of the LCFS regulation (California Code of Regulations, title 17, §95485 (a)(1)) specifies the current energy densities of California reformulated gasoline (115.63 megajoules per gallon), natural gas (0.98 megajoules per scf), and other transportation fuels. Those Table 4 values are the only ones that may be used for reporting fuel transactions under the LCFS. For example, it is not appropriate to convert pounds to scf using the figure 5.66 lbs. of natural gas per gallon of gasoline, because that figure was derived (by the National Institute of Standards and Technology) from gasoline and natural gas energy density values which are different from those appearing in Table 4 of the LCFS regulation.[1]

CNG is typically dispensed in units of pounds. Regulated parties must therefore convert pounds of CNG sold into scf in order to complete their quarterly and annual LCFS reports. This conversion is accomplished as follows:

1. Divide total pounds of CNG sold by the mass density of natural gas. The CA-GREET 1.8b mass density value of 20.4 grams/scf should be used for this purpose[2].

2. Convert the result to scf using the standard conversion factor of 453.59 grams/lb. Example: 100 lbs CNG would be converted to scf of CNG as follows:

$$100\ lbs\ CNG \times \frac{SCF}{20.4\ grams} \times \frac{453.59\ grams}{lb} = 2{,}223.48\ SCF$$

[1] National Institute of Standards and Technology, 2005. SPECIFICATIONS, TOLERANCES, AND OTHER TECHNICAL REQUIREMENTS FOR WEIGHING AND MEASURING DEVICES, NIST Handbook, 44. Standard S.5.1. of that document ("Marking of Gasoline Volume Equivalent Conversion Factor") states that a device dispensing compressed natural gas shall have either the statement "1 Gasoline Liter Equivalent (GLE) is Equal to 0.678 kg of Natural Gas" or "1 Gasoline Gallon Equivalent (GGE) is Equal to 5.660 lb of Natural Gas" permanently and conspicuously marked on the face of the dispenser according to the method of sale used. (Added 1994) The NIST standard is based on the following1994 energy density values for U.S. gasoline and natural gas: 114,118 Btu/gal for gasoline and 20,161 Btu/lb for natural gas. For comparison with the energy density values appear in Table 4 of the LCFS regulation, these values convert to about 120.39 megajoules per gallon for gasoline and 0.96 megajoules per scf for natural gas. The corresponding Table 4 values are given in this Advisory.

[2] California-Modified Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation model (CA-GREET), Version 1.8b. Cell E45, "Fuel_Specs" tab. CA-GREET is available for download at http://www.arb.ca.gov/fuels/lcfs/ca_greet1.8b_dec09.xls

Source: California Air Resources Board

APPENDIX C: Relationships Among Organic Gas Terms

The following, *Relationships Among Organic Gas Used in the Emissions Inventory,* defines some terms used in the next appendix.

Relationships Among Organic Gas Terms
Used in the Emission Inventory

MOTOR VEHICLES:

1. **NMHC** (non-methane hydrocarbons) + **methane** (hydrocarbons) **= HC** [or **THC** total hydrocarbons]

-- NMHC and HC (THC) contain only hydrocarbons (not oxygenated compounds like aldehydes) due to GC-FID measurement technique

-- NMHC and HC must be adjusted for the oxygenated compounds to get NMOG

2. **NMHC** (non-methane hydrocarbons) **----------**> (adjusts oxygenated cmpds to add)

NMOG (non-methane organic gas)

3. **NMOG** (non-methane organic gas) + **methane =** ~**TOG** (approximately Total Organic Gas)

OVERALL INVENTORY:

4. **TOG** x **FROG** (Fraction of Reactive Organic Gas) = **ROG** (Reactive Organic Gas)

5. **TOG x FR_VOC** (Fraction of Volatile Organic Cmpds) = **VOC** (Volatile Organic Cmpds)

- VOC is U.S. EPA term -- uses a separate federal list of exempted cmpds

6. **TOG** - Exempt cmpds [ARB list of methane, ethane, CFCs, etc.] = **ROG**

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APPENDIX D: Percentage and Grams Criteria Emissions

Excerpts from CA-GREET2.0-t1.xlsm[16]

Acronyms

CIDI means compression ignition direct injection combustion engine, commonly called "diesel".

Vehicle classes defined in the California LEV II, the low emission vehicle regulations:

- PC means Passenger Car
- LDT1 means a light-duty truck with loaded weight of 0 to 3750 pounds
- LDT2 means a light-duty truck with gross vehicular weight of 3751 to 8500 pounds

[16] LCFS Lifecycle Analysis Website https://ww2.arb.ca.gov/resources/documents/lcfs-life-cycle-analysis-models-and-documentation

Table D-1 shows the well-wheels energy and emission changes.

Argonne National Laboratory **GREET Transportation Fuel Cycle Analysis Model**

Table D-1: Well-to-Wheels Energy and Emission Changes

	A	B	C	D
1939	**3. Well-to-Wheels Energy and Emission Changes (%, r e)**			
1940		**Gasoline Vehicle: CA gasoline**	**Gasoline Vehicle: Low-Level EtOH Blend with Gasoline (E10, Corn, dry)**	**Dedicated CNGV, NA NG**
1941	Total Energy	4.8%	0.0%	-11.8%
1942	Fossil Fuels	5.4%	0.0%	-6.0%
1943	Coal	-3.6%	0.0%	-84.9%
1944	Natural Gas	54.7%	0.0%	596.9%
1945	Petroleum	-2.2%	0.0%	-99.5%
1946	CO2 (w/ C in VOC & CO)	5.2%	0.0%	-25.2%
1947	CH4	12.3%	0.0%	177.2%
1948	N2O	1.5%	0.0%	-15.3%
1949	GHGs	5.4%	0.0%	-18.6%
1950	VOC: Total	-0.3%	0.0%	-37.2%
1951	CO: Total	-0.3%	0.0%	3.3%
1952	NOx: Total	-11.2%	0.0%	0.5%
1953	PM10: Total	-5.9%	0.0%	-42.2%
1954	PM2.5: Total	-3.0%	0.0%	-44.3%
1955	Sox: Total	-1.9%	0.0%	-49.9%

Source: Argonne National Lab

Results Tab

Natural gas (North America) **CA-GREET 2.0 T1 model** **AKK 2/2/16**

Criteria Pollutants Reduced or Increased Comparing Diesel Fueled to Natural Gas Fueled Vehicles (Table D-2).

Table D-2: Diesel to Natural Gas Criteria Pollutant Change

	CIDI Vehicle, Conventional and Low Sulfur Diesel (g/MJ)	Dedicated CNGV, North Am NG (g/MJ)	Change (g/MJ)
CO_2 (w/ C in VOC & CO)	98.529	66.457	(32.072)
CH_4 (methane)	0.13290	0.33089	0.19799
N_2O (Nitrous oxide)	0.00244	0.00374	0.00130
GHGs	102.577	75.844	(26.733)
VOC: Total	0.02067	0.03779	0.01712
CO: Total	0.06639	0.61817	0.55178
NOx: Total	0.06792	0.07260	0.00468
PM10: Total	0.01028	0.00588	(0.00440)
PM2.5: Total	0.00738	0.00371	(0.00367)
SOx: Total	0.02524	0.01404	(0.01120)

Source: Argonne National Lab

From CA-GREET2.0-Tier 1. See Appendix E for details of assumptions

Comparing Diesel Fueled to Natural Gas Fueled Vehicles, PM10, PM2.5 and SOx decreased while the total VOC, CO and NOx increased.

Results Tab

2015 scenario **Results Tab**

LD Trucks 2 **CA-GREET 2.0 T1 Model** **Akk 2/2/16**

Table D-3 shows the emission for conventional and LS diesel.

Argonne National Laboratory **GREET Transportation Fuel Cycle Analysis Model**

Table D-3: Conventional and LS Diesel CIDI Emissions

	A	B	C	D	E	F	G	H	I
564	**CIDI Vehicle: Conventional and LS Diesel**								
565		**J/mile or g/mile**				**J/MJ or g/MJ**			
566	Item	**Feedstock**	**Fuel**	**Vehicle Operation**	**Total**	**Feedstock**	**Fuel**	**Vehicle Operation**	**Total**
567	Total Energy	761,561	1,116,772	6,081,452	7,959,786	125,227	183,636	1,000,000	1,308,863
568	Fossil Fuels	748,955	1,108,590	6,081,452	7,938,997	123,154	182,290	1,000,000	1,305,444
569	Coal	13,267	8,850	0	22,117	2,182	1,455	0	3,637
570	Natural Gas	680,542	788,981	0	1,469,524	111,905	129,736	0	241,640
571	Petroleum	55,146	310,758	6,081,452	6,447,356	9,068	51,099	1,000,000	1,060,167
572	CO2 (w/ C in VOC & CO)	59	89	451	599	10	15	74	99
573	CH4	0.634	0.171	0.003	0.808	0.104	0.028	0.001	0.133
574	N2O	0.001	0.002	0.012	0.015	0.000	0.000	0.002	0.002
575	GHGs	76	94	454	624	12	15	75	103
576	VOC: Total	0.024	0.033	0.069	0.126	0.004	0.005	0.011	0.021
577	CO: Total	0.045	0.074	0.285	0.404	0.007	0.012	0.047	0.066
578	NOx: Total	0.141	0.107	0.165	0.413	0.023	0.018	0.027	0.068
579	PM10: Total	0.011	0.012	0.039	0.062	0.002	0.002	0.006	0.010
580	PM2.5: Total	0.010	0.010	0.025	0.045	0.002	0.002	0.004	0.007
581	SOx: Total	0.042	0.108	0.003	0.154	0.007	0.018	0.001	0.025

Source: Argonne National Lab

Results Tab

2015 scenario

LD Trucks 2 **CA-GREET 2.0 T1 model** **Akk 2/2/16**

Table D-4 shows the well-to-wheels energy consumption and emissions.

Argonne National Laboratory **GREET Transportation Fuel Cycle Analysis Model**

Table D-4: Well-to-Wheels Energy Consumption and Emissions

	A	B	C	D	E	F	G	H	I
564	**2. Well-to-Wheels Energy Consumption and Emissions: per mile and per mmBtu Dedicated CNGV, NA NG**								
565		**J/mile or g/mile**				**J/MJ or g/MJ**			
566	Item	**Feedstock**	**Fuel**	**Vehicle Operation**	**Total**	**Feedstock**	**Fuel**	**Vehicle Operation**	**Total**
567	Total Energy	915,795	358,782	7,085,187	8,359,764	129,255	50,638	1,000,000	1,179,893
568	Fossil Fuels	911,883	328,278	7,085,187	8,325,348	128,703	46,333	1,000,000	1,175,036
569	Coal	4,123	32,056	0	36,178	582	4,524	0	5,106
570	Natural Gas	876,748	287,430	7,085,187	8,249,366	123,744	40,568	1,000,000	1,164,312
571	Petroleum	31,013	8,792	0	39,804	4,377	1,241	0	5,618
572	CO2 (w/ C in VOC & CO)	52	20	399	471	7	3	56	66
573	CH4	2.132	0.058	0.155	2.344	0.301	0.008	0.022	0.331
574	N2O	0.014	0.001	0.012	0.027	0.002	0.000	0.002	0.004
575	GHGs	110	22	406	537	15	3	57	76
576	VOC: Total	0.083	0.004	0.181	0.268	0.012	0.001	0.026	0.038
577	CO: Total	0.285	0.021	4.074	4.380	0.040	0.003	0.575	0.618
578	NOx: Total	0.352	0.028	0.134	0.514	0.050	0.004	0.019	0.073
579	PM10: Total	0.004	0.002	0.036	0.042	0.001	0.000	0.005	0.006
580	PM2.5: Total	0.003	0.002	0.021	0.026	0.000	0.000	0.003	0.004
581	SOx: Total	0.081	0.017	0.002	0.099	0.011	0.002	0.000	0.014

Source: Argonne National Lab

Results Tab

Natural gas (North America) **CA-GREET 2.0 T1 model** **AKK 2/2/16**

APPENDIX E: Criteria Pollutants from CA-GREET 2.0 T1 Model

The vast spreadsheet called CA-GREET can tell criteria pollutants produced by the full lifecycle of fuels in vehicles, including CNG. The 2015 update of the CA- GREET 2.0 T1 model and the documentation are at California Air Resources Website (https://ww2.arb.ca.gov/resources/documents/lcfs-life-cycle-analysis-models-and-documentation). Various results are expressed based on the various choices at the beginning. The following selections were used in the tool to find the criteria pollutants shown in Appendix D.

The download appears to hang (and then appears when the browser is closed); "save target as" works better.

Do you want to continue? Yes.

Save a copy.

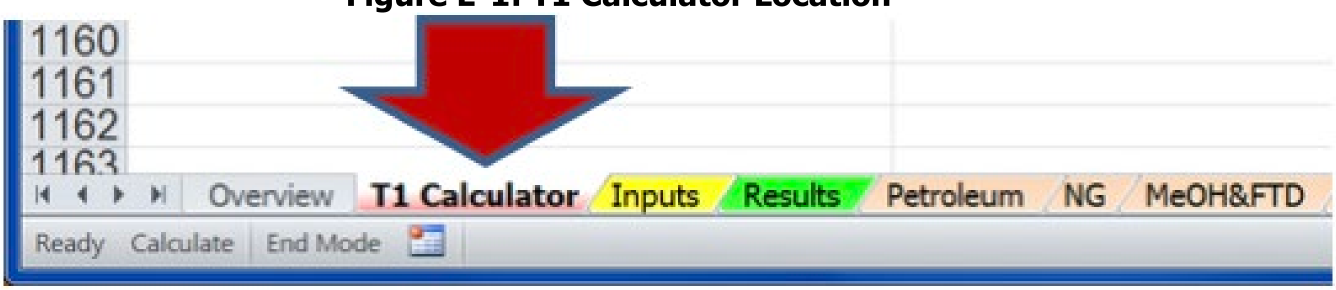
Among the many tabs, start at the "T1 Calculator" Tab.

There is nothing novel about the feedstock or fuel production from this grant. There are no user defined fields.

Note: The Automatic Calculation feature is disabled to avoid error messages stemming from GREET's use of circular calculation. Clicking on the Results tab will prompt GREET to recalculate the entire workbook whenever changes are made for input assumptions.

Figures E-1 through E-4 show how to use the T1 calculator and Tables E-1 through E-4 show menu choices for the T1 calculator.

Figure E-1: T1 Calculator Location



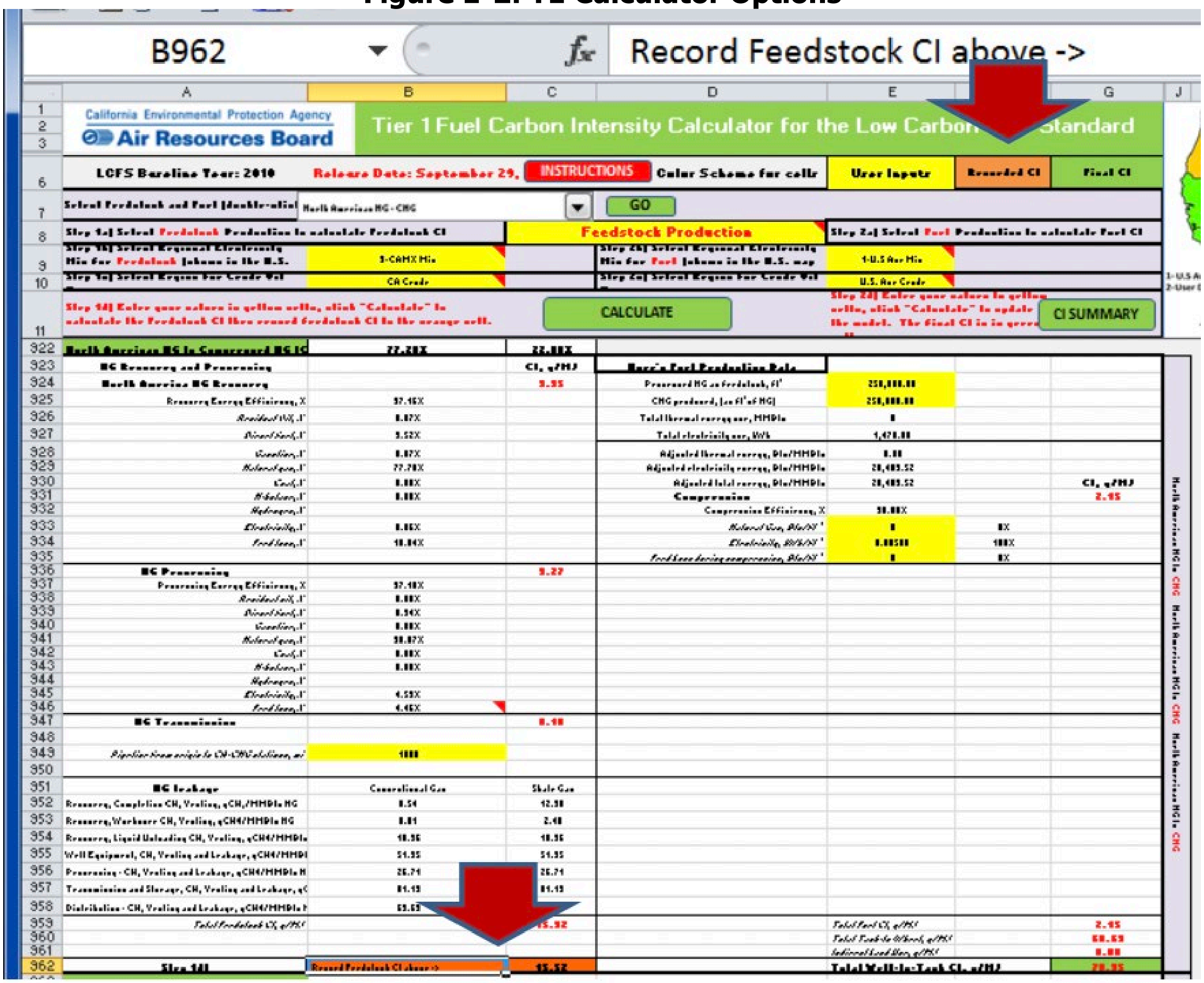
Source: California Air Resources Board

Table E-1: T1 Calculator Tab Menu Choices

Cell Number in T1 Calculator Tab	Drop Down Menu Choice
C7	Feedstock and Fuel = North American NG - CNG
Double-click GO	CI assumptions are row 920 – 962 but do not reflect our choices yet, so do not waste time examining them.
D8	Feedstock Production
C6	3-CAMX (Calif. Mix of electricity)
F7	CA Crude
D11	Double click Calculate (big green button). Wait.
From cell C962	Record Feedstock CI in ORANGE cell F6 before going to Fuel Production

Source: California Air Resources Board

Figure E-2: T1 Calculator Options



Source: California Air Resources Board

Table E-2: T1 Calculator Tab Menu Choices

<u>Cell Number in T1 Calculator Tab</u>	<u>Drop Down Menu Choice</u>
D8	Fuel Production
E9	3-CAMX (Calif. Mix of electricity)
E10	CA Crude
G11	Double click CI SUMMARY button for final CI (in G962)
OK	(Info for CI Summary is also in Q1 – X6)

Source: California Air Resources Board

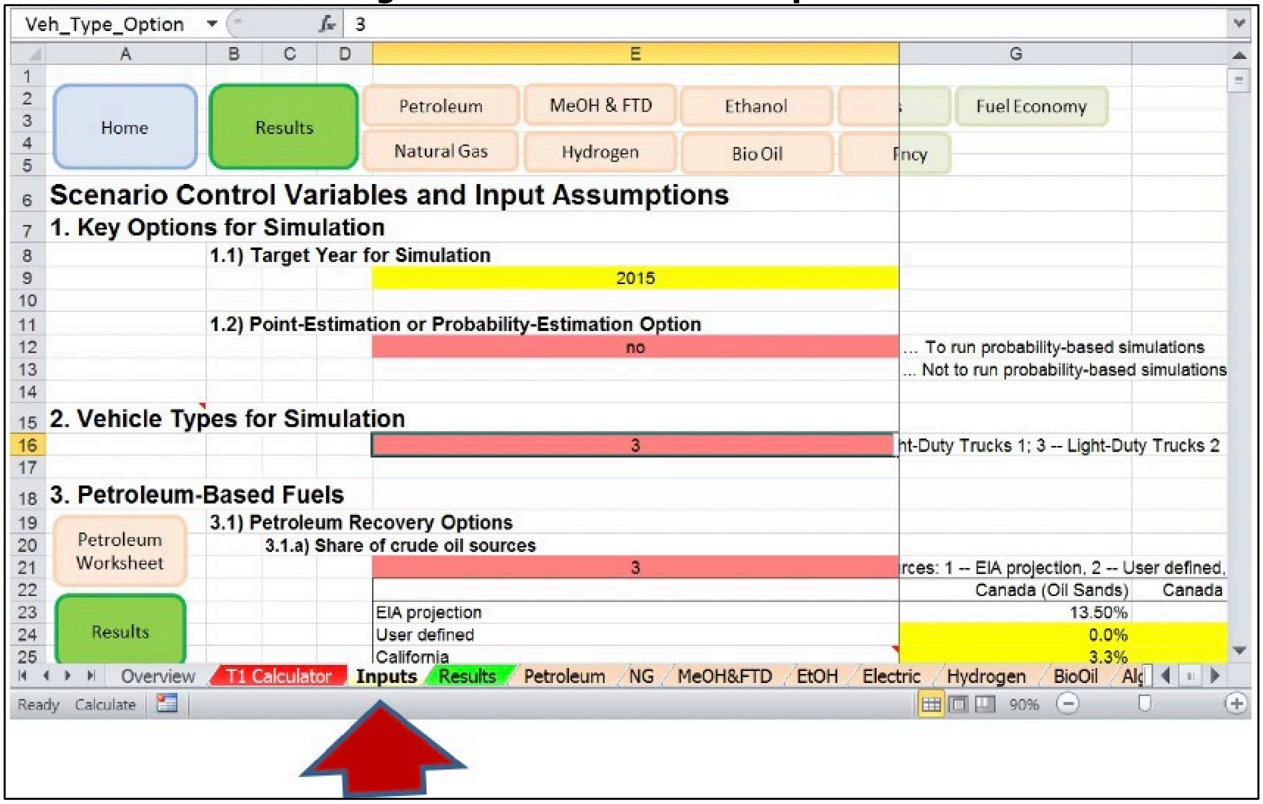
North American NG–CNG total Carbon Intensity is 78.35 g/MJ.

Table E-3: T1 Calculator Inputs

<u>Inputs Tab Cell Number</u>	<u>Description</u>	<u>Choice</u>
Display starts in high numbered rows	to get to top	Control > Home
	Scenario Control Variables and Input Assumptions	
E9	1.1) Target Year for Simulation	2015
E12	1.2) Point-Estimation or Probability-Estimation Option	No
E16	2. Vehicle Types for Simulation	3 = Light-Duty Trucks 2

Source: California Air Resources Board

Figure E-3: T1 Calculator Input Tab



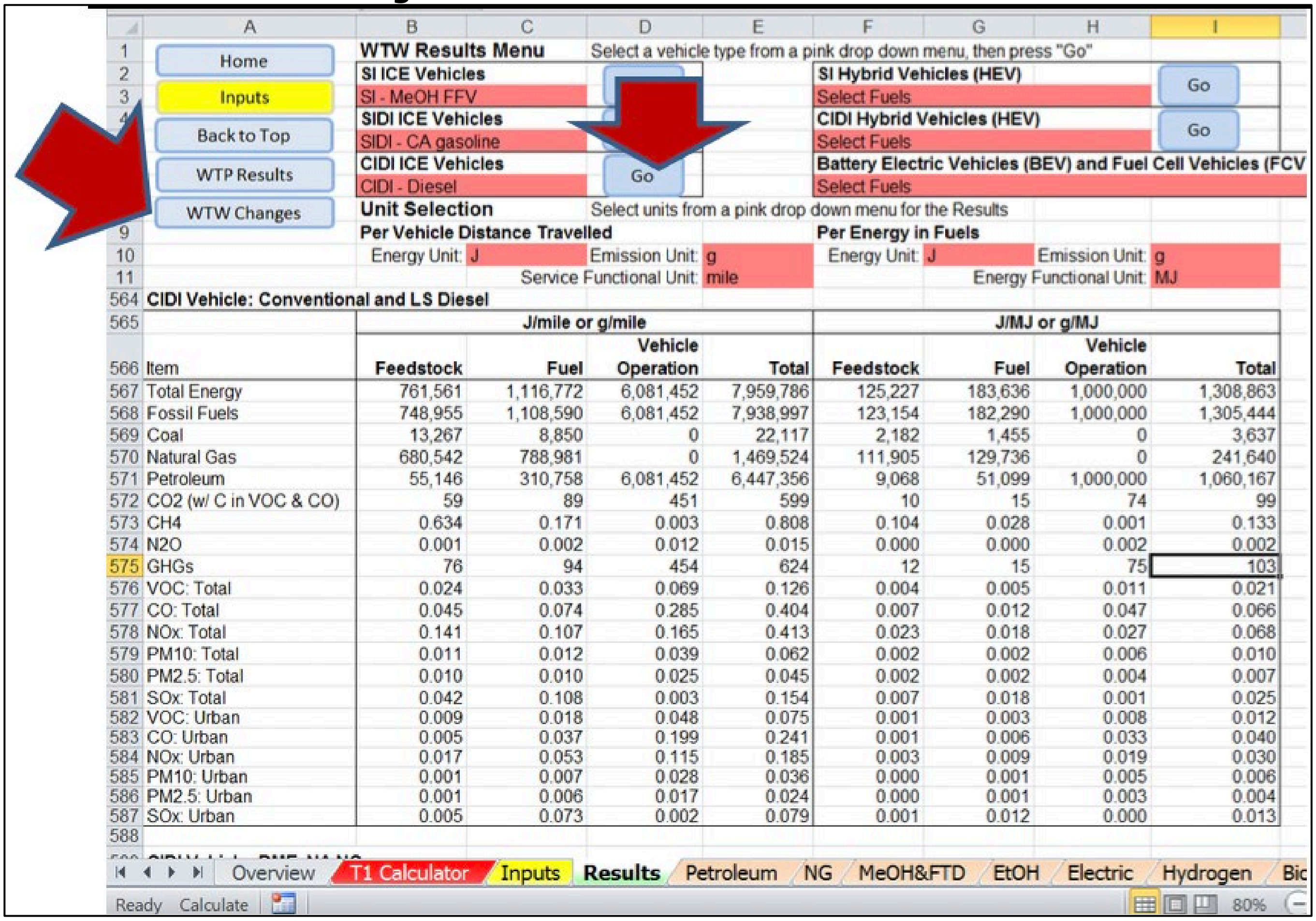
Source: California Air Resources Board

Table E-4: T1 Calculator Results Tab Choices

Results Tab Cell Number	**Description**	**Choice**
	Select units from a pink drop down menus in the Results Tab	
C10	Energy Unit:	J
G10	Energy Unit:	J
I11	Energy Functional Unit:	MJ
A8	Single click button WTW Changes See Row 1939 (Appendix D-1) Percentage Relative to E10 in Gas Vehicles (GV)	WTW Changes
	Hide column D	
	Set "print area" to A1939 to row E1955	
	Add something about the choices into the footer and print.	Save
	Unhide column	
D7	CIDI – Diesel Set "print area" to A564 to **I**581 (See Appendix D-3) CIDI Vehicle: Conventional and LS Diesel	Single click GO
Compare the diesel emissions to North American natural gas in rows 139 -156 manually.		

Source: California Air Resources Board

Figure E-4: T1 Calculator Results Tab



Home
Inputs
Back to Top
WTP Results
WTW Changes
WTW Results Menu
Select a vehicle type from a pink drop down menu, then press "Go"
SI ICE Vehicles
SI - MeOH FFV
SIDI ICE Vehicles
SIDI - CA gasoline
CIDI ICE Vehicles
CIDI - Diesel
Go
SI Hybrid Vehicles (HEV)
Select Fuels
Go
CIDI Hybrid Vehicles (HEV)
Select Fuels
Go
Battery Electric Vehicles (BEV) and Fuel Cell Vehicles (FCV
Select Fuels
Unit Selection
Select units from a pink drop down menu for the Results
Per Vehicle Distance Travelled
Energy Unit: J
Emission Unit: g
Service Functional Unit: mile
Per Energy in Fuels
Energy Unit: J
Emission Unit: g
Energy Functional Unit: MJ
CIDI Vehicle: Conventional and LS Diesel

	J/mile or g/mile				J/MJ or g/MJ			
Item	Feedstock	Fuel	Vehicle Operation	Total	Feedstock	Fuel	Vehicle Operation	Total
Total Energy	761,561	1,116,772	6,081,452	7,959,786	125,227	183,636	1,000,000	1,308,863
Fossil Fuels	748,955	1,108,590	6,081,452	7,938,997	123,154	182,290	1,000,000	1,305,444
Coal	13,267	8,850	0	22,117	2,182	1,455	0	3,637
Natural Gas	680,542	788,981	0	1,469,524	111,905	129,736	0	241,640
Petroleum	55,146	310,758	6,081,452	6,447,356	9,068	51,099	1,000,000	1,060,167
CO2 (w/ C in VOC & CO)	59	89	451	599	10	15	74	99
CH4	0.634	0.171	0.003	0.808	0.104	0.028	0.001	0.133
N2O	0.001	0.002	0.012	0.015	0.000	0.000	0.002	0.002
GHGs	76	94	454	624	12	15	75	103
VOC: Total	0.024	0.033	0.069	0.126	0.004	0.005	0.011	0.021
CO: Total	0.045	0.074	0.285	0.404	0.007	0.012	0.047	0.066
NOx: Total	0.141	0.107	0.165	0.413	0.023	0.018	0.027	0.068
PM10: Total	0.011	0.012	0.039	0.062	0.002	0.002	0.006	0.010
PM2.5: Total	0.010	0.010	0.025	0.045	0.002	0.002	0.004	0.007
SOx: Total	0.042	0.108	0.003	0.154	0.007	0.018	0.001	0.025
VOC: Urban	0.009	0.018	0.048	0.075	0.001	0.003	0.008	0.012
CO: Urban	0.005	0.037	0.199	0.241	0.001	0.006	0.033	0.040
NOx: Urban	0.017	0.053	0.115	0.185	0.003	0.009	0.019	0.030
PM10: Urban	0.001	0.007	0.028	0.036	0.000	0.001	0.005	0.006
PM2.5: Urban	0.001	0.006	0.017	0.024	0.000	0.001	0.003	0.004
SOx: Urban	0.005	0.073	0.002	0.079	0.001	0.012	0.000	0.013

Overview | T1 Calculator | Inputs | Results | Petroleum | NG | MeOH&FTD | EtOH | Electric | Hydrogen | Bic
Ready Calculate 80%

Source: California Air Resources Board

APPENDIX F: Formaldehyde Emissions of Vehicles

A vehicle and fuel together have certain emission caps. Auto manufacturers certify every vehicle for operation on the fuel to the State of California. "The Air Resources Board adopted the first *California Low-Emission Vehicle Regulations* (LEV) regulations in 1990, requiring automobile manufacturers to introduce progressively cleaner light- and medium-duty vehicles with more durable emission controls..."[17] The *California Low-Emission Vehicle Regulations* require all vehicles in California, including compressed natural gas fueled vehicles, to have limited formaldehyde emissions.

The pertinent sections of the regulations[18]:

- § 1960.1(e)(2) Formaldehyde exhaust emission standards for 1993-2003 model methanol-fueled passenger cars, light-duty trucks and medium-duty vehicles.
- § 1960.1(e)(3) Formaldehyde exhaust emission standards for 1992-2006 model LEV I TLEVs, LEVs, ULEVs and SULEVs in the passenger car, light-duty truck, and medium- duty vehicle classes.

All 2001 and subsequent model passenger cars, light-duty trucks and medium-duty vehicles certified to the LEV I or LEV II standards will be subject to the CAP 2000 certification procedures – the "California Exhaust Emission Standards and Test Procedures for 2001 and Subsequent Model Passenger Cars, Light-Duty Trucks and Medium-Duty Vehicles," incorporated by reference in section 1961(d). This document is also available on the ARB's Internet site and incorporates the federal test procedures contained in subparts B, C and S, Part 86, Title 40, Code of Federal Regulations with modifications for the California program.

Trucks were allowed up to 40 mg/mile[18] formaldehyde emissions in 2012 during LEVII, which was reduced to 6 mg/mile in the October 2015 regulations[19] for LEV III, shown in Table F-1 and Table F-2.

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17 California Air Resources Board Low-Emission Vehicle Regulations
http://www.arb.ca.gov/regact/2014/leviii2014/leviii14isor.pdf

18 California Air Resources Board Low Emission Vehicle Program https://ww2.arb.ca.gov/our-work/programs/advanced-clean-cars-program/lev-program/low-emission-vehicle-greenhouse-gas

19 California Air Resources Board Low-Emission Vehicles 2014
http://www.arb.ca.gov/regact/2014/leviii2014/leviii2014.htm

Table F-1: 2015 Emission Standards

LEV III Exhaust Mass Emission Standards for New 2015 and Subsequent Model Passenger Cars, Light-Duty Trucks, and Medium-Duty Vehicles[3]						
Vehicle Type	Durability Vehicle Basis (mi)	Vehicle Emission Category[2]	NMOG + Oxides of Nitrogen[4] (g/mi)	Carbon Monoxide (g/mi)	Formaldehyde (mg/mi)	Particulates[1] (g/mi)
All PCs; LDTs 8500 lbs. GVWR or less; and MDPVs Vehicles in this category are tested at their loaded vehicle weight	150,000	LEV160	0.160	4.2	4	0.01
		ULEV125	0.125	2.1	4	0.01
		ULEV70	0.070	1.7	4	0.01
		ULEV50	0.050	1.7	4	0.01
		SULEV30	0.030	1.0	4	0.01
		SULEV20	0.020	1.0	4	0.01
MDVs 8501 - 10,000 lbs. GVWR, excluding MDPVs Vehicles in this category are tested at their adjusted loaded vehicle weight	150,000	LEV395[5,6]	0.395	6.4	6	0.12
		ULEV340[5,6]	0.340	6.4	6	0.06
		ULEV250	0.250	6.4	6	0.06
		ULEV200	0.200	4.2	6	0.06
		SULEV170	0.170	4.2	6	0.06
		SULEV150	0.150	3.2	6	0.06
MDVs 10,001-14,000 lbs. GVWR Vehicles in this category are tested at their adjusted loaded vehicle weight	150,000	LEV630[5,6]	0.630	7.3	6	0.12
		ULEV570[5,6]	0.570	7.3	6	0.06
		ULEV400	0.400	7.3	6	0.06
		ULEV270	0.270	4.2	6	0.06
		SULEV230	0.230	4.2	6	0.06
		SULEV200	0.200	3.7	6	0.06

Source: California Air Resources Board

(2) *"LEV III" Particulate Standards.*

As Amended: September 2, 2015

Date of Hearing: October 23, 2014

Table F-2: 2004-2019 Emission Standards

LEV II Exhaust Mass Emission Standards for New 2004 through 2019 Model LEVs, ULEVs, and SULEVs in the Passenger Car, Light-Duty Truck and Medium-Duty Vehicle Classes							
Vehicle Type	Durability Vehicle Basis (mi)	Vehicle Emission Categoy	NMOG (g/mi)	Carbon Monoxide (g/mi)	Oxides of Nitrogen (g/mi)	Formaldehyde (mg/mi)	Particulates (g/mi)
All PCs; LDTs 8500 lbs. GVWR or less Vehicles in this category are tested at their loaded vehicle weight	50,000	LEV	0.075	3.4	0.05	15	n/a
		LEV, Option 1	0.075	3.4	0.07	15	n/a
		ULEV	0.040	1.7	0.05	8	n/a
	120,000	LEV	0.090	4.2	0.07	18	0.01
		LEV, Option 1	0.090	4.2	0.10	18	0.01
		ULEV	0.055	2.1	0.07	11	0.01
		SULEV	0.010	1.0	0.02	4	0.01
	150,000 (Optional)	LEV	0.090	4.2	0.07	18	0.01
		LEV, Option 1	0.090	4.2	0.10	18	0.01
		ULEV	0.055	2.1	0.07	11	0.01
		SULEV	0.010	1.0	0.02	4	0.01
MDVs 8501 - 10,000 lbs. GVWR Vehicles in this category are tested at their adjusted loaded vehicle weight	120,000	LEV	0.195	6.4	0.2	32	0.12
		ULEV	0.143	6.4	0.2	16	0.06
		SULEV	0.100	3.2	0.1	8	0.06
	150,000 (Optional)	LEV	0.195	6.4	0.2	32	0.12
		ULEV	0.143	6.4	0.2	16	0.06
		SULEV	0.100	3.2	0.1	8	0.06
MDVs 10,001-14,000 lbs. GVWR Vehicles in this category are tested at their adjusted loaded vehicle weight	120,000	LEV	0.230	7.3	0.4	40	0.12
		ULEV	0.167	7.3	0.4	21	0.06
		SULEV	0.117	3.7	0.2	10	0.06
	150,000 (Optional)	LEV	0.230	7.3	0.4	40	0.12
		ULEV	0.167	7.3	0.4	21	0.06
		SULEV	0.117	3.7	0.2	10	0.06

Source: California Air Resources Board