Equivalent Strategies for the ARB Zero Emission Bus Regulation

June 2014 Edition

Prepared for:

Southern
California
Gas Company

A Sempra Energy utility®

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Gladstein, Neandross & Associates (GNA) has extensive experience in the alternative-fuel, electric vehicle and low emission transportation technology industries. Over the last twenty years, GNA has assisted with the successful development and implementation of many of the nation's most significant alternative fuel vehicle and refueling infrastructure projects in transit, refuse, municipal, local pick-up and delivery, regional trucking, port drayage, yard hostler, and long-haul trucking applications. GNA has worked with LA Metro, Valley Metro in Phoenix, OCTA in Orange County, Long Beach Transit, New York City MTA and a host of other transit providers interested in reducing emissions and costs through the use of alternative fuels.

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Photo by Neil Kremer, www.flickr.com/photos/neilarmstrong2/

Acronyms & Abbreviations

AB	Assembly Bill
AC Transit	Alameda-Contra Costa Transit District
ARB	California Air Resources Board
BAF	A Clean Energy company specializing in conversion systems for alternative fuel vehicles
bhp-hr/mi	Brake horsepower hour per mile
CA	California
CNG	Compressed natural gas
CO_2	Carbon dioxide
CWI	Cummins Westport, Incorporated
DPF	Diesel particulate filter
EGR	Exhaust gas recirculation
FTA	Federal Transit Administration
g/bhp-hr	Grams per brake horsepower hour
GGE	Gasoline gallons equivalent
GHG	Greenhouse gases
GNA	Gladstein, Neandross and Associates
GREET	Greenhouse gases, Regulated Emissions, and Energy Use in Transportation
H/CNG	Hydrogen blended with compressed natural gas
IPCC	Intergovernmental Panel on Climate Change
ISL G	Cummins Westport 8.9-liter natural gas engine
k	Thousand
kWh	Kilowatt hour
LA Metro	Los Angeles County Metropolitan Transportation Authority
LCFS	Low Carbon Fuel Standard
LLC	Limited Liability Company
M	Million
MBRC	Miles between road calls
NOx	Oxides of nitrogen
NREL	National Renewable Energy Laboratory
PM	Particulate matter
SCR	Selective catalytic reduction
TTW	Tank-to-wheel
TWC	Three-way catalyst
UC	University of California
ULSD	Ultra Low Sulfur Diesel
VTA	Santa Clara Valley Transportation Authority
WTT	Well-to-tank
WTW	Well-to-wheel
ZBus	Zero emission bus

Executive Summary

In February 2000, the California Air Resources Board adopted the Fleet Rule for Transit Agencies which includes a requirement that larger transit agencies begin to purchase buses with zero exhaust emissions ("zero emission buses"). This zero emission bus purchase requirement was originally scheduled to begin in 2008, but only after a demonstration phase in which participating transit agencies procured and successfully operated qualifying buses. This report covers two of the three technologies which, by regulation, qualify to meet the zero emission bus requirements, namely hydrogen fuel cells and electric batteries. The third technology, catenary electric buses, are not covered in this report.

The original April 2012 edition of this report was prepared upon completion of the initial round of zero emission bus demonstration projects and midway through a second demonstration. The intent of the second phase was to demonstrate zero emissions buses on a larger scale with the hope of eliminating the operational and financial challenges experienced during the initial demonstration. After an initial round of demonstration projects, fuel cell buses were approximately 4.5 times as expensive to purchase, only 15 percent as reliable and cost $4.60 per mile more to operate than a natural gas bus, which had become the standard technology in the South Coast Air Basin. The operational and financial challenges experienced during the initial demonstration prompted a delay in the purchase requirement schedule while the second advanced demonstration was implemented.

As a follow-up to the original edition of this report, the June 2014 edition has been prepared to incorporate the final results of the second round of advanced demonstration projects, which recently became available. In addition to evaluating the results, the June 2014 edition includes: updates to the technology and operational cost assumptions used in the model, revisions to the fuel pathway values, an assessment of the current state of fuel cell technology compared to recently released DOE/FTA cost and performance targets, and an analysis of additional hydrogen and electric fuel pathways.

The advanced demonstration placed twelve additional hydrogen fuel cell vehicles in California transit agencies between 2009 and 2011. Significant improvements were realized between the two demonstration phases. However, one year into the second phase, these buses are about 3.3 times more expensive to purchase, only 50 percent as reliable and cost $3.41 per mile more to operate than a natural gas bus. Despite significant progress towards commercial viability, the advanced demonstration still indicates that it will take many more years for zero emission buses to meet the operational needs of transit agencies with respect to reliability and cost effectiveness. In the meantime, the opportunity to encourage other promising technologies and to reduce smog-forming, toxic and greenhouse gas pollutants from transit operations is being missed, and the emission reductions which were supposed to begin in 2008 are not being realized.

While the development of zero emission technologies is an important goal, it is even more crucial to immediately reduce the exposure of transit-dependent Californians to the adverse public health impacts of poor urban air. As we wait for the maturation of these zero emission buses, other alternative fuel technologies can match or exceed the needed emission reductions at a cost that transit agencies can afford today. Not only are these options more cost effective than the current zero emission buses, they provide equivalent or even superior emission reductions when considering the well-to-wheel environmental impact.

Natural gas is already quite prevalent as a transit bus fuel and offers greater than 23 percent reduction in greenhouse gas emissions compared to diesel buses. For years, natural gas engines also typically produced 40 percent less oxides of nitrogen emissions than their diesel counterparts, and eliminate emissions of toxic diesel particulate. Hybrid technology, renewable natural gas and advanced after-treatment can further reduce oxides of nitrogen and greenhouse gas emissions from today's transit buses. These are lower cost technologies that can provide near zero emission levels. This analysis suggests that there are other currently available strategies that can provide and exceed the total emission reduction benefit expected from the current zero emission bus regulation at a cost savings of up to 42 percent.

In order to obtain badly needed emission reductions sooner and to encourage the fuel neutral development of zero and near zero emission technologies, the California Air Resources Board should consider revising their technology forcing regulation and provide transit agencies greater flexibility to meet the net emissions reductions attributed to the zero emission bus purchase requirement. Transit agencies should be allowed to use whatever combination of technologies that best meets the operational, invested capital, and fiscal requirements of the subject transit agencies, while maintaining the integrity of their service and avoiding a degradation in the same.

Recommendation:

- Implement an emissions reduction performance requirement on new purchases rather than requiring a specific technology; an example being:
  - 15 percent reduction of engine/vehicle NOx totals on all new vehicles.
  - Reduction of GHG totals on all new vehicles.
- Continue advance demonstrations and analysis of zero and near zero technologies.
- Modify the California Code of Regulations, Title 13, Sections 2023.1 – 2023.4 to include the option to use near zero technologies that provide equivalent or greater emission reductions than would result from the current regulations.

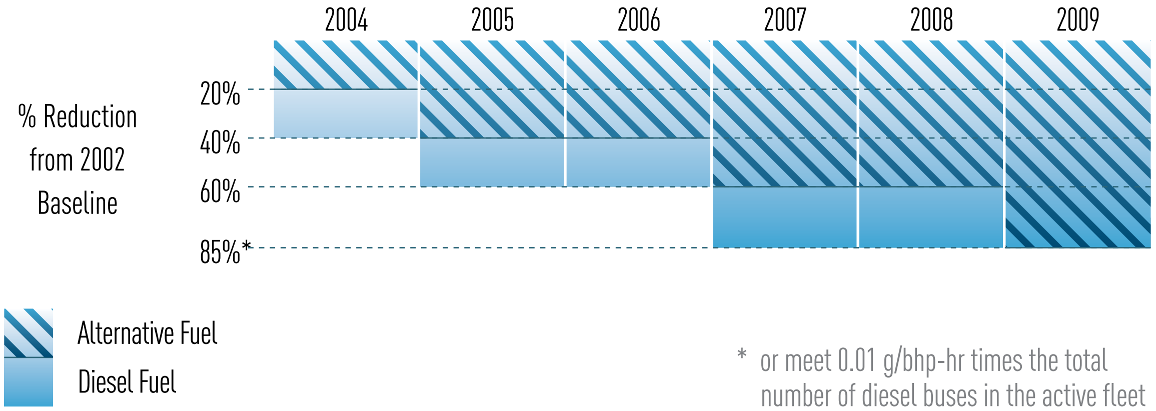
Background

Transit Fleet Rule

The California Air Resources Board (ARB) adopted the Fleet Rule for Transit Agencies in February 2000. The purpose of this rule was to reduce both criteria pollutants and exposure to toxic air contaminants from urban buses and transit fleet vehicles "…while also providing flexibility to such fleet operators to determine their optimal fleet mix in consideration of such factors as air quality benefits, service availability, cost, efficiency, safety, and convenience…"[1] The regulation affects both public transit operators and heavy-duty engine manufacturers. Typically, urban buses are owned by a public transit agency, primarily operated in intra-city/county service, and normally powered by a heavy-duty diesel or natural gas engine. Through 2006, new urban buses operated in California had to meet the more stringent California Urban Bus engine exhaust emission standard. Starting with the 2007 model year, the California Urban Bus standard aligned with the California heavy-duty engine exhaust emission standard.

ARB's Fleet Rule required that transit agencies choose either an alternative-fuel or diesel "fuel path". A transit agency's fuel path choice determined urban bus purchase requirements and emission reduction deadlines – agencies that chose the diesel fuel path must achieve more substantial emission reductions from their baseline sooner, and were required to begin purchasing zero emission buses earlier as well. The Fleet Rule's emissions reduction requirements were performance-based, and did not dictate the process or technology used to achieve the required emission reductions. This provided flexibility by allowing each transit agency to determine the best way for their operation to achieve these significant emission reductions. The transit operators had the flexibility to purchase cleaner vehicles, retire older vehicles, or retrofit vehicles with advanced after-treatment devices in order to comply with fleet average NOx emissions requirements. The NOx fleet average could not exceed 4.8 g/bhp-hr by October 1, 2002. PM reductions were required over several years and varied depending on the fuel path chosen by the transit operator, as shown in Table 1.

Table 1: PM reduction timeline



* or meet 0.01 g/bhp-hr times the total number of diesel buses in the active fleet

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[1] Title 13, California Code of Regulation, Section 2023.1 (a)t

Zero Emission Bus (ZBus) Regulation

In addition to the fleet average NOx and PM emission reduction targets required by the Fleet Rule, transit agencies that operate 200 or more buses are subject to a zero emission bus ("ZBus") demonstration and purchase requirement. A ZBus is defined as producing zero exhaust emissions of any criteria or precursor pollutant under any and all possible operational modes and climates. Buses that meet these requirements include battery electric buses, electric trolley buses with overhead twin wire power supply, and hydrogen fuel cell buses. As originally drafted, the ZBus section of the Fleet Rule for Transit Agencies required ZBus demonstrations by diesel path agencies starting in 2006, with eventual purchases starting in 2008. Purchases by alternative-fuel path agencies were required by 2009. Starting in these years, 15 percent of a transit agency's new bus purchases were required to be ZBuses. As drafted, the ZBus regulation would require eleven fleets that operate nearly 6,700 buses to purchase approximately 74 ZBuses annually.

Battery Electric Bus

The ZBus regulation was modified first in 2004 and again in 2006. The most recent changes, approved by the ARB Board in 2006, delayed the ZBus purchase requirement to 2011 for diesel path agencies and 2012 for alternative-fuel path agencies. As part of these amendments, the Board added a second advanced demonstration for diesel path agencies. The reason for these delays and the second phase of zero emission bus demonstrations was due to the exorbitant cost of qualifying ZBus technologies, operational problems with zero emission demonstration units and the recognition that the vehicles were not commercially ready.

Hydrogen Fuel Cell Bus

As drafted, the ZBus regulation would require eleven fleets that operate nearly 6,700 buses to purchase approximately 74 ZBuses annually.

Electric Trolley Bus

The first phase of demonstrations involved seven (7) hydrogen fuel cell buses, three (3) with Santa Clara Valley Transportation Authority (VTA) and San Mateo County Transit, three (3) with Alameda- Contra Costa Transit District (AC Transit) and Golden Gate Transit, and the seventh with SunLine Transit Agency in the Coachella Valley. The demonstration deployed two fuel cell bus configurations into the fleets; hydrogen fuel cell buses and hybrid hydrogen fuel cell buses. In the former, the electric energy produced by the fuel cell is delivered directly to the electric motors which convert it to motive power. In hybrid hydrogen fuel cells, electric energy is delivered to an energy storage device, such as a battery or capacitor, which delivers it to the electric motors as needed. With the addition of an energy storage device, hybrid hydrogen fuel cells provide the ability to recoup energy during braking events by operating the electric motors in reverse. Commonly referred to as regenerative braking, the process effectively provides resistance to aid in slowing a vehicle in addition to generating electricity which is delivered and stored in the energy storage device. The first phase demonstration buses cost in excess of $3 million each.[2] The three hydrogen fuel cell buses at VTA were fuel cell buses with no hybrid technology, performed with fuel economy worse than that of VTA's diesel buses, and suffered miles between road calls (MBRC) at 10 percent of that of their diesel buses.[3] AC Transit's three buses were hybrid hydrogen fuel cell buses and had much better fuel economy - almost 70 percent better than their diesel counterparts. However, these buses also had extremely substandard reliability; averaging just over 10 percent of the diesel MBRC. SunLine Transit's hybrid hydrogen fuel cell bus had the best fuel economy of the three demonstrations, but still achieved only 2,200 MBRC; versus 14,000 for their diesel buses.[4]

The cost of the second phase hybrid hydrogen fuel cell buses is still quite high at over $2.2 million each; compared to just over $450,000 for a natural gas bus.

As a result of the poor performance and high cost of the fuel cell buses in the first demonstration, a second phase demonstration was required. A total of 12 hybrid hydrogen fuel cell buses are part of the second phase demonstration, which is being conducted through a joint partnership of five Bay Area transit agencies. These buses were supposed to be in service by January 2009. However, due to problems in securing funds and lengthy production schedules, delivery of these buses was delayed. The 12th new demonstration bus was received by transit agencies and put into service in November of 2011. The cost of the second phase hybrid hydrogen fuel cell buses is still quite high at over $2.2 million each;[5] compared to just over $450,000 for a natural gas bus.

Due to the delay in implementing the second demonstration and resultant lack of data demonstrating commercial feasibility, the ARB decided to postpone the ZBus purchase requirement in July 2009 by issuing a notice stating that they would not enforce the purchase requirement date identified in the current regulations. At that time, the ARB did not select a definitive date for the reinstatement of the purchase requirement. However, the ARB considered several specific implementation criteria (see Table 2), as well as a greenhouse gas emissions criterion, that would serve as metrics intended to trigger the mandatory purchase requirement when the technology met these milestones. Although ARB staff proposed the demonstration criteria below for review, the Board took no action to adopt any of them. In what appeared to be a sign of indecisiveness regarding what performance characteristics exemplify a commercially viable technology, the Board requested that the ARB staff do further research and return with an update by the summer of 2012. As of April 2014, no notable update has been released by the ARB staff.

Table 2: ARB ZBus proposed implementation criteria

	Implementation Criteria	Current State of Fuel Cell Technology
Purchase Cost (Fuel Cell Bus vs. Electric Trolley)	1.25:1	2.75:1
Durability/Warranty	20,000 hours	8,000 – 12,000 hours
Reliability (Miles Between Road Calls)	10,000 miles	2,500 miles

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[2] Santa Clara Valley Transportation Authority and San Mateo County Transit District Fuel Cell Transit Buses: Evaluation Results, Technical Report NREL/TP-560-40615, November 2006, Kevin Chandler/Battelle, Leslie Eudy/NREL

[3] Status Report on the Zero Emission Bus Regulation, Air Resources Board Meeting, July 23, 2009, San Diego, CA

[4] Ibid.

[5] Ibid.

Concurrently, the Department of Energy (DOE) was also working on ways to evaluate the status of fuel cell technology in transit applications. In March 2012, the DOE published a similar version of performance, cost and durability targets (see Table 3) based on an evaluation of demonstration efforts by the National Renewable Energy Laboratory (NREL).[6] These "market-driven targets represent technical requirements needed to compete with alternative technologies."[7] While some of the DOE's targets are redundant to the implementation criteria defined by the ARB, they are more comprehensive. Because of this, the ARB appears to have started using them as an assessment tool for the state of fuel cell bus technology. However, despite the ARB's utilization of the DOE's targets, as of this writing, ARB has not officially adopted these targets to trigger the purchase requirements. Hence the regulation is still in limbo.

In addition to the demonstration projects being pursued in California, other important evaluations of ZBus technology are taking place. These other studies help provide context and valuable additional perspective on the readiness of these important transportation technologies that the ARB has mandated California transit agencies deploy. One of the most important studies is that being conducted by NREL.

Table 3: DOE Fuel Cell Bus Targets and Current Status[6,7]

	Current Average	Current Range	2016 Target	Ultimate Target
Bus Lifetime	n/a	1–3.5 years 9,899–64,227 miles	12 years 500,000 miles	12 years 500,000 miles
Power Plant Lifetime	n/a	940–13,843 hours	18,000 hours	25,000 hours
Bus Availability	69%	31–81%	85%	90%
Fuel Fills	1 per day	n/a	1 per day (<10 min)	1 per day (<10 min)
Bus Cost	$ 2,000,000	n/a	$1,000,000	$600,000
Power Plant Cost	n/a	n/a	$450,000	$200,000
Hydrogen Storage Cost*	n/a	n/a	$75,000	$50,000
Road Call Frequency (Bus/ Fuel Cell System)	2,728/11,043 miles between road calls (MBRC)	344–6,057/1,734–36,339 MBRC	3,500/15,000 MBRC	4,000/20,000 MBRC
Operation Time	n/a	7–19 hours per day/ 2–7 days per week	20 hours per day/ 7 days per week	20 hours per day/ 7 days per week
Scheduled and Unscheduled Maintenance Cost**	n/a	n/a	$0.75/mile	$0.40/mile
Range		227–347 miles	300 miles	300 miles
Fuel Economy	6.8 miles per gallon diesel equivalent	5.8–7.3 miles per gallon diesel equivalent	8 miles per gallon diesel equivalent	8 miles per gallon diesel equivalent

* Cost projected to a production volume of 400 systems per year.

** Excludes mid-life overhaul of power plant.

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[6] U.S. Department of Energy, Fuel Cell Technologies Program Record #12012, *Fuel Cell Bus Targets*, March 2, 2012

[7] National Renewable Energy Laboratory, *Fuel Cell Buses in U.S. Transit Fleets: Current Status 2013*, NREL/TP-5400-60490, December 2013

Including buses that are being demonstrated in British Columbia, there are 38 fuel cell buses currently operating in North America.

NREL recently released *Fuel Cell Buses in U.S. Transit Fleets: Current Status 2013*,[7] which is their latest version of a series of reports summarizing the progress of fuel cell electric bus development in the United States. Including buses that are being demonstrated in British Columbia, there are 38 fuel cell buses currently operating in North America. Using data collected from August 2012 to July 2013, this latest NREL evaluation characterizes the status of the technology and compares it to the established DOE fuel cell bus targets. During the period covered, the cost of a fuel cell bus was found to be $2 million. This also happens to be the cost documented in NREL's 2012 status report which indicates that the technology has not realized any reductions in cost over the period and remains far above the DOE's 2016 target of $1 million.

Equally important to a transit agency is "availability", which is the percentage of days that buses are planned for operation compared to the percentage of days that the buses are actually available. During the reporting period of the NREL's 2013 status report, fuel cell buses were found to have an average availability of 69 percent. While buses improved from just 60 percent as stated in NREL's 2012 status report, availability of the current fuel cell buses still remain far from the DOE's 2016 target of 85 percent which is easily achieved by today's natural gas transit buses. Further complicating the evaluation of current status is the large disparity between the observed low of 31 percent and the high of 81 percent availability achieved by different demonstration buses during the evaluation period.

Fuel cell buses achieved a miles between road calls (MBRC) of 2,738 miles for the bus, 3,999 for the propulsion system and 11,043 for the fuel cell system. The MBRC's for both the bus and the fuel cell system improved during the reporting period as compared to the 2012 status of 2,500 for the bus and 10,000 for the fuel cell system. However, it should be noted that there is significant variability in the results which makes it difficult to fully evaluate the current status given the relatively small sample size. This is clearly evident in the range of MBRC for the bus and fuel cell system. The MBRC for the bus ranged from a low of 344 to a high of 6,057. Similarly, the MBRC for the fuel cell ranged from a low of 1,374 to a high of 36,339.

While fuel cell buses continue to progress towards commercial readiness, there are clear indications that they will not achieve DOE's 2016 fuel cell bus targets.

In addition to the demonstration status update, the NREL report provided an evaluation using the DOE's Technology Readiness Assessment Guide[8] for each fuel cell bus manufacturer. The Technology Readiness Level (TRL) is a framework for evaluating its progress through the commercialization process from basic research/concept to deployment. There are 9 levels that represent progression through the 5 phases of the commercialization process. For example, TRL 9 is the last level of the commercialization process and corresponds to deployment. The technologies from each of the five manufacturers currently operating in North America were evaluated. Those manufactured by Van Hool, New Flyer and El Dorado were found to be most reflective of TRL 7 which corresponds to the demonstration/commissioning phase of the commercialization process. Proterra and EBus were found to be most reflective of TRL 6 which corresponds to a technology which is midway between the development and demonstration/commissioning phases of the commercialization process. These assessments are reflective of the results from the demonstrations. While fuel cell buses continue to progress towards commercial readiness, there are clear indications that they will not achieve DOE's 2016 fuel cell bus targets.

Concurrent with the hydrogen fuel cell bus developments, similar progress has been made deploying and demonstrating battery electric buses which appear to show potential cost advantages over hybrid hydrogen fuel cell buses. An example of this is the Proterra EcoRide, of which Foothill Transit Agency has three. The cost of a battery electric bus has decreased $100-200k over the last couple years. With a delivery cost of just $850,000, the grid-powered electric bus is approximately 40 percent of the cost of the latest hybrid hydrogen fuel cell buses. Capable of travelling 25 to 50 miles between charges and requiring only 10 minutes to completely recharge, Foothill Transit believes this bus can work in over 60 percent of their existing service routes. Initially, this system required the addition of charging stations every 30 miles that can recharge by producing 500-kW of power at an approximate cost of $1 million each.[9] However, recent developments in inductive charging methods have introduced lower cost alternatives capable of providing en-route overhead and in-ground charging. While much of this charging will need to occur during periods of peak electrical demand, the CPUC has provided transit agencies with a flat rate which eliminates the demand charge. The CPUC's flat rate structure is provided to transit fleets via a temporary three-year tariff. After three years, the CPUC believes that the rate structure will no longer be needed because the demand charge will be absorbed over a larger number of electric buses within an individual transit fleet. In the absence of this rate structure, the

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[8] Department of Energy, Technology Readiness Assessment Guide, G 143.3-4a, September 2011

[9] Conversation with George Karbowski, Director of Operations and Maintenance, Foothill Transit, November 23, 2010

addition of one electric bus would increase the peak energy demand of the facility resulting in a higher demand charge that must be taken into account when evaluating the cost per mile of battery electric buses. It is also not clear whether local power infrastructure would be able to bear the strain of the added load if electric buses were to be deployed in a significant way, possibly necessitating costly modifications to wires and transformers.

With continued progress towards commercial readiness of both hybrid hydrogen fuel cell and battery electric buses, the ARB held its first ZBus workshop in over two years in September 2013, along with a second workshop in December 2013. The purpose of these meetings was to review the status of the technology and vehicle demonstrations with both fleets and equipment manufacturers. Material presented at the workshop confirmed that the second advanced demonstration has resulted in significant progress towards the FTA/DOE targets. At the conclusion of the second workshop, the ARB agreed to continue assessing the status of the technology by conducting stakeholder interviews/outreach and site visits. At the December 2013 workshop, ARB announced that a third workshop would be held in late April/early May 2014 to present its findings along with an outline of the draft regulatory approach. However, the date of the third workshop has been delayed and is currently anticipated to be held in late June/early July 2014. The delays to the workshop schedule will likely impact the date in which the final regulatory approach will be presented to the ARB Board for approval. As originally scheduled and currently shown on the books, the final regulatory approach was to be presented to the ARB Board for approval in December 2014. However, the delays experienced are likely to push out the date for ARB Board approval to April 2015. Although there is uncertainty surrounding the dates and potential changes to the regulatory approach, the proposed language will likely include all transit agencies and contain provisions designed to achieve near term emission reductions while continuing the longer term push to zero.

Despite signs of progress towards commercial readiness, it is clear that a gap remains between the current state of the technology and the targets set forth by the ARB, the FTA and the DOE. Although ZBus technology has made significant strides towards commercial feasibility. Unfortunately, the results from the demonstration vehicles reveal that the technology is not ready for commercial adoption.

CNG Bus

Alternative to Current ZBus Regulation

In 2012, Gladstein, Neandross & Associates (GNA) prepared a report for Southern California Gas Company that analyzed the existing ZBus regulation and assessed whether readily available technologies and/or low carbon fuels could provide the same environmental benefit as the ZBus Regulation at a lower cost. At that time, the report confirmed that these commercially available alternative technologies could yield comparable environmental benefits at a lower cost and could be implemented years ahead of qualifying ZBus technologies. Since preparation of the initial report, significant progress has been made demonstrating qualifying ZBus technologies which have resulted in improved performance and reduced capital costs. Such technological advancements have introduced the need to reevaluate the assumptions used in the analysis. As evaluated in the initial report, the baseline technologies considered were current model year natural gas and diesel engines; both now certified to the 0.2 g/bhp-hr NOx emission standard. Hybrid hydrogen fuel cells and battery electric buses were considered as the baseline for ZBus technology. Additional technologies considered were:

The report confirmed that these commercially available alternative technologies could yield comparable environmental benefits at a lower cost and could be implemented years ahead of qualifying ZBus technologies.

- Renewable natural gas
- Hybrid-electric (natural gas or diesel)
- Hydrogen blended natural gas
- Advanced after-treatment

Along with the technologies listed above, the analysis evaluated various possible fuel pathways for each ZBus technology in order to yield a more comprehensive comparison of the environmental benefits of the ZBus regulations versus those that could be achieved through alternative fuels and technologies. In order to conduct this analysis in a manner that was both transparent and understandable, GNA used information from ARB resources as much as possible. This enables the reader to review the sources of emission factors, technology performance, costs, and other pertinent data. The primary sources of information for this report were as follows:

- ARB's Low Carbon Fuel Standard (LCFS)
- Modified CA-GREET 1.8b model, December 2009. A modified version of Argonne National Laboratories' GREET (Greenhouse gases, Regulated Emissions, and Energy use in Transportation) model developed by Life Cycle Associates, LLC and the California Air Resources Board. ARB used this model in AB 32 analysis.
- Detailed California-Modified GREET Pathway for Transportation Fuels
- ARB Carl Moyer cost-effectiveness calculations
- ARB ZBus presentations and handouts
- ARB Executive Orders
- US Department of Transportation reports:
    - » Federal Transit Administration FTA-WV-26-7004.2007.1, Transit Bus Life Cycle Cost and Year 2007 Emissions Estimation
    - » DOT-T-07-01, Fuel Cell Bus Life Cycle Cost Model: Base Case & Future Scenario Analysis
- US Department of Energy reports:
    - » Fuel Cell Technologies Program Record #12012, Fuel Cell Bus Targets

- Society of Automotive Engineers research paper 2009-01-1950, Using Hythane as a Fuel in a 6-Cylinder Stoichiometric Natural-gas Engine
- National Renewable Energy Laboratory reports:
    - NREL/TP-560-40615, Santa Clara Valley Transportation Authority and San Mateo County Transit District Fuel Cell Transit Buses: Evaluation Results
    - NREL/TP-5600-57560, SunLine Transit Agency Advanced Technology Fuel Cell Bus Evaluation: Fourth Results Report
    - NREL/PR-560-42665, Fuel Cell Bus Evaluation Results
    - NREL/TP-5400-60490, Fuel Cell Buses In U.S. Transit Fleets: Current Status 2013
    - NREL/TP-5400-60603, BC Transit Fuel Cell Bus Project: Evaluation Results Report
- California Fuel Cell Partnership, A Road Map for Fuel Cell Electric Buses in California – A zero emission solution for public transit, March 2013
- Institute of Transportation Studies (UC Davis) presentation, Hydrogen Enriched Natural Gas Technology
- Published data from original equipment manufacturers (Cummins Westport, BAF)
- Discussions with manufacturers and retailers (Cummins Westport, Air Products, New Flyer Industries, North American Bus Industries)

Cost Effectiveness Methodology

To determine if readily available technologies and/or low carbon fuels could provide the same environmental benefit at a lower cost than qualifying ZBus technologies, an analysis was performed to determine the NOx and GHG emissions from each prospective technology. The emissions of each pollutant were converted into a standard, easy-to-compare metric of grams per mile (g/mi). The cost effectiveness ($ per mass of pollutant reduced) for each technology was calculated after determining the total cost per mile. The cost effectiveness was used as the standard metric to determine which alternative provided the greatest environmental benefit for the least cost. Below is a description of the calculated values used to determine each technology's cost effectiveness:

Tank-to-Wheel NOx Emissions

NOx emissions were determined as tailpipe out (tank-to-wheel or TTW) and were calculated using the latest ARB certification standards for diesel and natural gas engines. The certification standard of 0.2 g/bhp- hr was then converted to g/mi with the conversion of 4.0 bhp-hr/mi as is used by the ARB for an estimation of the power needed per mile per hour of speed traveled for an urban bus.

Well-to-Tank NOx Emissions

Well-to-tank (WTT) NOx emissions for each powertrain configuration and fuel, except in the case of hybrid hydrogen fuel cells, were determined using CA-GREET values for each fuel pathway. WTT NOx emissions for hybrid hydrogen fuel cells were generated using CA-GREET to model specific scenarios.

Well-to-Wheel NOx Emissions

Well-to-wheel (WTW) NOx emissions were calculated by summing the TTW NOx emissions and WTT NOx emissions.

Well-to-Wheel Greenhouse Gas Emissions

Well-to-wheel greenhouse gas emissions were based on the fuel economy of the technology and calculated by using the CA-GREET model or Detailed California-Modified GREET Pathway documents. All GHG emissions are WTW emissions.

Capital Cost per Mile

Capital cost for each technology was determined from the recent average capital cost of the bus amortized over a 500,000 mile life. The Federal Transit Agency (FTA), which typically funds at least 80 percent of the cost of each new bus, requires transit agencies to operate FTA supported buses for a minimum of 12-years or 500,000 miles.

Operations and Maintenance (O&M) Cost per Mile

For currently available transit bus technologies (using a diesel and CNG based powertrain), a first order approximation of O&M cost was calculated based on the initial capital cost of the bus. The O&M cost per year was assumed to be 1/60 of the capital cost.[10] This value was divided by the miles travelled per year; 41,667 miles (500,000 mile life/12 year life). It is more difficult to determine maintenance costs for newer technologies. In some cases these technologies may have a much higher cost for maintenance until the technology matures and improves. In other cases, the technology is maintained by the original equipment manufacturer under warranty as the market is developed and, thus, the true maintenance costs are difficult to ascertain because they are hidden and unknown to the public. Where sufficient data was available, O&M costs for qualified ZBus technologies were determined based on ARB, DOT/FTA or DOE demonstration project data.

Fuel Cost per Mile

Fuel cost per mile was determined from the price of the fuel per diesel gallon equivalent and the energy efficiency of the bus in miles per gallon. The fuel cost included the cost of any required fueling infrastructure.

Total Cost per Mile

The total cost per mile was determined by summing each technology's calculated capital cost per mile, O&M cost per mile and fuel cost per mile.

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[10] Z-TUG Inventory Alternatives Study, Final Report – H_2 and Natural Gas Transit Vehicles; CalStart; July 28, 2009

Model Values and Assumptions

A total of thirteen engine/power train and fuel pathway configurations were analyzed in order to evaluate a full spectrum of technologies; ranging from the most basic conventional diesel power train to a hybrid hydrogen fuel cell powertrain powered by hydrogen gas produced using electrolysis. Given the varying degrees of operational and cost data available for each configuration, assumptions were occasionally required in order to generate an easy-to-compare metric which would enable the cost-effectiveness for each configuration to be compared. The following section describes the configurations modeled, key characteristics and any assumptions that were required to complete the analysis.

Diesel Powertrain Configurations

Two diesel powertrain configurations were modeled in the analysis; a conventional diesel and a hybrid diesel powered transit bus. The cost for the conventional diesel transit bus was determined by obtaining quotes from the two largest bus manufacturers selling to the California urban bus market. Similarly, the cost for the diesel hybrid bus was determined through conversations with the Regional Sales Managers of both North American Bus Industries (NABI) and New Flyer Industries, the two largest full size transit bus manufacturers in the US. These values vary slightly from the values used by ARB staff in the past, but we feel these values are more accurate and fairly represent an apple to apple comparison. Operations and maintenance costs were determined using the relationship defined in the preceding section. Emissions values for the diesel engine were determined using the emission certification standards, whereas, the emissions of the hybrid powertrain were determined based on ARB's allowance for diesel hybrids to take credit for a 25 percent reduction in NOx levels over the diesel engine certification level.[11] This same 25 percent reduction in NOx was used as a reduction in fuel consumed and a corresponding reduction in GHG emissions. A summary of the diesel powertrain assumptions used for the analysis is included below:

Table 4: Diesel powertrain configurations and fuel pathways

Powertrain Fuel Pathway Configuration	Fuel Pathway	Capital Cost	Fuel Economy (miles/diesel equivalent gallon)	Operation & Maintenance ($/mile)	Fuel Cost ($/diesel equivalent gallon)
Diesel – Conventional	ULSD001	$412,000	4.17	$0.17	$4.12* + $2.70/DEF (used at 1/50 rate of diesel)
Diesel – Hybrid	ULSD001	$580,000	5.56	$0.23	$4.12* + $2.70/DEF (used at 1/50 rate of diesel)

* US Department of Energy, Energy Information Administration, US On-Highway Diesel Fuel Prices; average of 6 months California ULSD price per gallon from 7/22/2013 to 1/13/2014

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[11] California Interim Certification Procedures for 2004 and Subsequent Model Hybrid-Electric Vehicles, in the Urban Bus and Heavy-Duty Vehicle Class; State of California, Air Resources Board, October 24, 2002

CNG Powertrain and Fuel Pathway Configurations

Five natural gas transit bus powertrain configurations were modeled in the analysis; a conventional CNG, CNG hybrid, CNG with advanced after-treatment, CNG fueled with 100 percent renewable natural gas and CNG blended with hydrogen. Similar to the diesel configurations above, the cost of the conventional CNG transit bus was determined by obtaining quotes from the two largest bus manufacturers selling to the California urban bus market. Since CNG hybrid buses are still in the prototype stage, the price for those buses was determined by using the cost adder from CNG versus a diesel bus applied to the cost of the diesel hybrid bus.[12] Additionally, the same credit allowed by the ARB for the diesel hybrid was used for the natural gas hybrid, thus, allowing the natural gas hybrids to take credit for a 25 percent reduction in NOx levels over the natural gas engine certification level and a 25 percent reduction in fuel consumed and a corresponding reduction in GHGs.

Cummins Westport Three Way Catalyst

GNA revisited a previous discussion regarding the idea of advanced after-treatment with Cummins Westport, Inc. (CWI). CWI's ISL G engine has been the predominant natural gas engine in the transit market since its introduction and certification to 0.2 g/bhp-hr NOx in August 2007.[13] While the currently certified ISL G uses a three-way catalyst (TWC), CWI believes it is possible to achieve near zero NOx certification levels with its spark ignited natural gas engines. CWI has considered manufacturing a "super" catalyst for their current ISL G that would be capable of further reducing the already low NOx emissions from the engine package. They've also considered adding selective catalyst reduction (SCR) technology to the ISL G, although their preferred after-treatment for this engine package is a "super" TWC. While a larger TWC with more precious metal, properly designed and configured, could lead to substantial NOx reductions, achieving and the target of 85 percent lower NOx emissions would likely require a combination of enhancements to the catalyst coating and improving engine combustion characteristics. Further, better detection and controls would be required in order to manage and mitigate areas across the duty-cycle where elevated NOx levels typically occur. Despite of these challenges, CWI firmly believes that these spark ignited natural gas engines can achieve emissions levels on the order of 85 percent lower than their currently certified engine package without compromising fuel efficiency. As cost was not contemplated at this point in the discussions, GNA modeled this technology using the cost of the SCR catalysts that have been used by Cummins for their diesel engines.

After researching hydrogen blended natural gas in the latest stoichiometric natural gas engines, like the CWI ISL G noted above, it was determined that hydrogen blending most likely offers little or no advantage in those engines. Hydrogen blended natural gas generated significant NOx emissions reductions in the previous generation of lean-burn natural gas engines. Operating a natural gas engine in lean conditions results in lower combustion temperatures, and is the primary means to reduce the formation of NOx during the combustion

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[12] Conversation with Chris Dabbs and Mark Fisher, Regional Sales Managers at North American Bus Industries and New Flyer, respectively, June 30, 2011

[13] ARB Executive Order A-021-0457-1

process.[14] Hydrogen promotes the complete combustion of natural gas at leaner engine conditions than would otherwise be possible if no hydrogen was present. This further reduces combustion temperatures and reduces NOx emissions. Lean-burn natural gas engines were successfully certified with NOx emission levels between 1.2 and 1.8 g/bhp-hr in the past. Those same engines with hydrogen blended natural gas, and associated retuning, demonstrated NOx emission levels around 0.2 g/bhp-hr. However, those hydrogen blended, lean-burn, natural gas engines were never certified to the ARB 0.2 g/bhp-hr standard. Until recently, the only natural gas internal combustion engine ARB certified with NOx levels at 0.2 g/bhp-hr was the CWI ISL G engine that operates with exhaust gas recirculation (EGR), stoichiometric combustion and a three-way catalyst.[15] Since these engines don't run lean, adding hydrogen doesn't aid in reducing combustion temperatures and therefore will not provide substantial NOx reductions.

It should be noted that Hythane Company (which promotes an 80 percent natural gas/20 percent hydrogen blend) believes that hydrogen blended natural gas in an engine designed with EGR and stoichiometric combustion will substantially reduce NOx emissions. They claim that by operating the engine with slightly more fuel than is necessary for stoichiometric combustion, unburned hydrogen will pass through to the three-way catalyst and increase the effectiveness of the converter to reduce NOx and other emissions. Additionally, the addition of hydrogen to the fuel will allow increased quantities of EGR.[16] While in theory this may well be true, at this time the claim has not been independently verified, so we have not included this technology/fuel combination in our modeling.

Doosan recently certified a lean-burn natural gas engine with ARB that uses an SCR catalyst to meet the 0.2 g/bhp-hr standard for NOx.[17] This is only the second engine to do so in the heavy heavy-duty or urban bus engine class.[18] Since this is a lean burn natural gas engine, it is possible that using hydrogen blended natural gas in this engine to achieve leaner engine operation with its SCR catalyst could provide substantial NOx reductions well below the 0.2 g/bhp-hr certification standard and may someday be considered another near zero emissions technology.

Renewable Natural Gas Plant

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[14] Lean burn operating conditions are achieved by reducing the amount of fuel or increasing the amount of oxygen injected into the combustion chamber, thereby increasing the air-to-fuel ratio to a point where you typically have 8% excess oxygen

[15] Stoichemetric operating conditions are achieved by creating the ideal air-to-fuel ratio within the combustion chamber, thereby resulting in combustion of all fuel and oxygen within the cylinder.

[16] Hythane proposal to CEC in 2009; www.newvistaresearch.com/files/CEC-Hythane-Proposal-001.pdf

[17] ARB Executive Order A-376-0006

[18] Heavy heavy-duty diesel engine (HHDDE) class, which includes engines in the urban bus class, are engines certified for use in vehicles with a gross vehicle weight rating (GVWR) of greater than 33,0000 lbs.

The price of natural gas was determined from averaging recent monthly citygate prices in California. This estimate was also used for the price of renewable natural gas based on Clean Energy's recent offering of renewable natural gas at the same price as their traditional natural gas offering. Compression costs are identical for typical pipeline natural gas or renewable natural gas. A summary of the CNG powertrain assumptions used for the analysis is included below:

Table 5: CNG powertrain configurations and fuel pathways

Powertrain Fuel Pathway Configuration	Fuel Pathway	Capital Cost ($)	Fuel Economy (miles/diesel equivalent gallon)	Operation & Maintenance ($/mile)	Fuel Cost ($/diesel equivalent gallon)
CNG – Conventional	CNG001	$455,000	3.75	$0.18	$1.76*
CNG – Hybrid	CNG001	$622,500	5.00	$0.25	$1.76*
CNG – Advanced After-treatment	CNG001	$464,000	3.75	$0.19	$1.76*
CNG – Hydrogen Blended	n/a	$460,000	3.75	$0.18	$2.27
CNG – 100% renewable	CNG003‡	$455,000	3.75	$0.18	$1.76**

‡ Fuel Pathway CNG003 refers to landfill gas. Other forms of renewable CNG may have different costs and emission benefits.

* Intelligence Press, Inc., Natural Gas Intelligence Firm Physical Price For Natural Gas Citygate Price in California; monthly average from August 2013 to October 2013 plus average Southern California transit cost of electricity, maintenance, and capital

** Renewable natural gas is currently offered by Clean Energy Fuels at the same price as conventional natural gas

Battery Electric Powertrain and Fuel Pathway Configurations

Two battery electric bus configurations were modeled in the analysis; one in which charging was performed at the depot and one in which charging was performed periodically during a route. The cost of battery electric buses has been revised since the original report. The cost for 40 foot battery electric buses was determined based on a November 2013 contract executed between LA Metro and BYD. Similar reductions in the cost of battery electric buses were reflected in a recent order by Transit Authority of River City (TARC) in Louisville, KY for ten Proterra electric buses.

The cost of electricity was determined based on the California Public Utility Commission's three-year tariff provided to transit agencies. Under TOU-GS-1 (Time-of-use - General Service - 01), transit operators in Southern California Edison's territory are eligible for a flat rate of approximately $0.16 per kilowatt hour (kWh).[19] This rate structure eliminates the demand charge that a transit operator would realize after deploying an electric bus within their fleet.[20] In the event a transit operator adds an electric bus to the fleet, it is likely that the operator's peak electricity demand will increase even though the period required for charging may be as short as fifteen minutes. The increase in peak demand will be accompanied by a

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[19] California Public Utilities Commission, ARB Workshop – Rates and Electric Transit Presentation, Adam Langton, September 2013

[20] Demand charge is a component of the cost of electricity that is based on the total amount of electricity used at any one time.

corresponding increase in the demand charge. Ultimately, this must be applied to the electric bus' cost per mile to operate. The temporary three-year tariff that is intended to provide reasonable electricity rates until electric bus adoption rates have increased. With increased adoption rates, demand rates could be diluted across many more kilowatt hours of charging. A simple comparison would be to consider the manner in which a transit operator fuels its diesel fleet. Attempting to fuel all the diesel buses at once would require a significant amount of infrastructure to support the high flow rate required. To avoid these added costs, the diesel buses are fueled in series which results in a much lower flow rate demand than if they were to all fuel at once. This is the same operational approach that is anticipated for electric buses. By charging them in series, the peak demand and corresponding demand charge can be minimized and diluted across the total amount of kilowatt hours required to charge the buses.

In addition to the cost of electricity, an electric bus powered by en route chargers will incur additional infrastructure costs that must be accounted for in cost of the fuel. For this analysis, it was assumed that a single en-route charger could be strategically placed and service two electric transit buses. These devices are still relatively new to the marketplace and have sold in very low volumes, costing as much as $500,000 each when installed. For the purpose of this analysis, it was assumed prices will come down quickly to approximately $200,000 per en route charger. Charger maintenance is estimated at $7,200 per year based on budgetary plans by Foothill Transit.[21] Amortized across two buses over a 15 year period at 5 percent interest, the charger and annual maintenance adds $0.31 per DGE to the cost of the fuel.

The operations and maintenance cost of the battery electric buses was determined using the relationship defined in the preceding section. The fuel economy for a 40-foot long battery electric bus was determined by using ARB's Low Carbon Fuel Standard's (LCFS) Energy Efficiency Ratio (EER) value of 2.7 times that of a similar diesel bus. A summary of the battery electric powertrain assumptions used for the analysis is included below:

Table 6: Battery electric powertrain configurations and fuel pathway

Powertrain Fuel Pathway Configuration	Fuel Pathway	Capital Cost	Fuel Economy (miles/diesel equivalent gallon)	Operation & Maintenance ($/mile)	Fuel Cost ($/diesel equivalent gallon)*
Battery Electric – Base Charging	ELC001	$850,000	11.25	$0.34	$6.41
Battery Electric – En-route Charging	ELC001	$850,000	11.25	$0.34	$6.72

* Fuel costs assumed an $0.16 per kWh which includes demand charges

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[21] Conversation with Lauren Cochran, Texas A&M Transportation Institute, April 25, 2014

Hybrid Hydrogen Fuel Cell Configurations

Four hybrid hydrogen fuel cell electric bus (FCEB) powertrain and fuel pathway configurations were modeled in the analysis in order to accurately evaluate the various hydrogen production methods and their respected pathway values. Descriptions for each of the hydrogen production scenarios evaluated in the analysis are listed below:

Table 7: Hydrogen production scenario pathway description

Type of H_2	H_2 Production Location	H_2 Production Method	H_2 Transportation and Distribution	H_2 Compression at Fueling Location
Compressed Gas	Central	Steam methane reformation	H_2 gas transported 50 miles to fueling station via pipeline	Yes
Compressed Gas	Distributed	Steam methane reformation	n/a	Yes
Liquid to Gas	Central	Steam methane reformation	H_2 liquid transported 50 miles to fueling station via tanker truck	No or minimal
Compressed Gas	Distributed	Electrolysis using photovoltaics	n/a	Yes via default energy mix

Fuel cell bus capital cost was assumed to be $1.5 million. This revised capital cost is roughly $500,000 less than the average capital cost of the 12 fuel cell buses purchased by the Bay Area transit agencies participating in the advanced demonstration program for the ARB. Fuel cell bus manufacturers have made recent claims that they can produce hybrid FCEB for $1.0 million. However, this price is predicated on an individual transit agency placing a single order of at least 40 buses and is not reflected in any of the actual transactions for which there is a written record. An order of this size by any single fleet seems unlikely until demonstration units can improve availability and MBRC. A capital cost of $1 million may be possible, however, assuming fuel cell technology reaches the 2016 performance targets defined by the DOE.

The fuel economy used for hydrogen hybrid fuel cell buses was based on the ARB LCFS Energy Economy Ratio of 1.9 when compared to diesel internal combustion engines. Since fuel cell buses have demonstrated a wide range of possible fuel economies, this factor seemed to match the average of the best of those demonstrated so far. The price of hydrogen varies greatly in various reports so GNA selected one of the lower reported prices, estimated to be $8.5[22] per kilogram for hydrogen produced via steam methane reformation. The price includes the cost of the natural gas, water, and the electricity used by the reformer and the compression equipment, and also includes the cost of amortized capital and maintenance. The price of hydrogen produced via solar photovoltaic electrolysis was assumed to be $13.50 per kilogram which is the near-term estimate based on a study conducted by the University of California Davis.[23] Given the low number of stations producing hydrogen via electrolysis, it

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[22] National Renewable Energy Laboratory. *SunLine Transit Agency Advanced Technology Fuel Cell Bus Evaluation: Fourth Results Report.* By L. Eudy and K. Chandler. NREL/TP-5600-57560. January 2013.

[23] University of California Davis, *Sustainable Transportation Energy Pathways – A Research Summary for Decision Makers*, Chapter 3: The Hydrogen Fuel Pathway, 2011

is difficult to establish an average price. However, a recent article quoted the retail price of hydrogen produced via onsite electrolysis at AC Transit's Emeryville, CA station to be $12-13 per kilogram.[24]

A summary of the fuel cell powertrain assumptions used for the analysis is included below:

Table 8: Hybrid hydrogen fuel cell powertrain configurations and fuel pathways

Powertrain Fuel Pathway Configuration	Fuel Pathway	Capital Cost ($)	Fuel Economy (miles/diesel equivalent gallon)	Operation & Maintenance ($/mile)	Fuel Cost ($/diesel equivalent gallon)
Hybrid FCEB	H_2 Gas, Central SMR	$1,500,000	7.92	$0.80	$9.23
Hybrid FCEB	H_2 Gas, Dist. SMR	$1,500,000	7.92	$0.80	$9.23
Hybrid FCEB	H_2 Liquid, Central SMR	$1,500,000	7.92	$0.80	$9.23
Hybrid FCEB	H_2 Gas, Electrolysis	$1,500,000	7.92	$0.80	$14.66

Summary of Analysis Assumptions

Using the assumptions defined above, a total cost per mile was determined for each of the technology options. This metric is later used to assess the overall environmental benefit of each technology and its cost effectiveness.

Table 9: Summary of total cost per mile for each technology and fuel pathway

Powertrain/Fuel Pathway Configuration	Total Cost Per Mile ($/mile)
Diesel – Conventional	$1.99
Diesel – Hybrid	$2.14
CNG – Conventional	$1.56
CNG – Hybrid	$1.84
CNG – Advanced After-treatment	$1.58
CNG – Hydrogen Blended	$1.71
CNG – 100% Renewable	$1.56
Battery Electric – Base Charging	$2.61
Battery Electric – En-route Charging	$2.64
FCEB – H_2 Gas, Central SMR	$4.97
FCEB – H_2 Gas, Distributed SMR	$4.97
FCEB – H_2 Liquid, Central SMR	$4.97
FCEB – H_2 Gas, Electrolysis	$5.65

* Total cost per mile includes vehicle/station capital, maintenance and fuel costs

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[24] New York Times, *Fuel Cells at Center Stage*, Bradley Berman, November 22, 2013

Results

GNA modeled each of the technologies using data and calculations discussed in the previous section to determine the overall cost-effectiveness for each of the technology and fuel pathway configurations. The NOx and GHG reductions and overall cost effectiveness are shown below in Table 10. The table is sorted by total cost per mile, with the lowest cost option at the top. The cost per ton of NOx or GHG reduced is contrasted with the 2010 diesel baseline technology. Numbers in parenthesis are negative numbers, indicating that emissions were reduced and total cost was also reduced from the baseline.

A modern natural gas bus has the absolute lowest cost per mile over the life of the modeled vehicles. Even though the bus is slightly more expensive and the maintenance costs of the natural gas bus are slightly higher than diesel, over a 12-year life the natural gas bus will provide a 22 percent savings over that of a diesel bus because of the reduced fuel expense.

Hybrid technology added between 8 and 18 percent to the total life cycle cost versus the same engine without hybrid technology. The bus is about 40 percent more expensive than the same bus without hybrid technology, but much of that extra cost for the bus and maintenance is returned due to the improved fuel economy. The benefit of this increase in life cycle cost is a 25 percent reduction in NOx and GHG emissions. It certainly is possible that hybrid technology, in high sales and production volumes, could become considerably cheaper than the 40 percent capital and maintenance cost adder used in this analysis, further reducing the total life cycle cost while maintaining the significant emissions advantage. In addition, many original equipment manufacturers feel that the fuel savings and NOx and GHG reductions from a hybrid bus are actually better than the 25 percent they are credited with by the ARB. Once ARB staff's proposed amendments to the heavy-duty hybrid vehicle certification procedure are adopted, the benefits of the hybrid system will become clearer. Until then, the California market for heavy-duty hybrids is likely to remain relatively small.

Table 10: Cost effectiveness of various technologies

Technologies	TTW NOx (g/mile)	WTW GHG (g/mile)	Cost per ton NOx reduced	Cost per ton GHG reduced	Total cost per mile
CNG – Conventional (2010 baseline)	0.8	2,607	n/a	($498)	$1.56
CNG – 100% Renewable	0.8	435	n/a	($133)	$1.56
CNG – Advanced After-treatment	0.12	2,607	($550k)	($473)	$1.58
CNG – Hydrogen Blended	0.8	2,688	n/a	($361)	$1.71
CNG – Hybrid	0.6	1,955	($673k)	($93)	$1.84
Diesel – Conventional (2010 baseline)	0.8	3,397	n/a	n/a	$1.99
Diesel – Hybrid	0.6	2,548	$687k	$162	$2.14
Battery Electric – Base Charging	0.0	1,593	$701k	$311	$2.61
Battery Electric – En-route Charging	0.0	1,593	$732k	$325	$2.64
FCEB – H_2 Gas, Central SMR	0.0	1,786	$3.4M	$1,674	$4.97
FCEB – H_2 Gas, Distributed SMR	0.0	1,771	$3.4M	$1,659	$4.97
FCEB – H_2 Liquid, Central SMR	0.0	2,411	$3.4M	$2,736	$4.97
FCEB – H_2 Gas, Electrolysis	0.0	123	$4.1M	$1,014	$5.65

Other possible advanced natural gas technologies like renewable natural gas or advanced after-treatment offer the possibility of significant reductions in emissions with small price increases. In the case of advanced after-treatment with CNG, the analysis shows that the total life cycle cost is still cheaper than a diesel bus while demonstrating an 85 percent reduction in NOx and a 23 percent reduction in GHG (when compared to the diesel baseline). The advanced after-treatment device only reduces NOx emissions, not GHGs, but using natural gas provides the 23 percent reduction in GHG emissions compared to diesel because natural gas has lower carbon intensity than petroleum based fuels. Even when taking into account the slightly lower fuel economy of natural gas buses when compared to diesel, natural gas buses still demonstrate considerably lower greenhouse gas emissions.

> **In fact, renewable natural gas buses produced only 18 to 27 percent of the WTW GHG emissions of even a "zero emission" battery electric powered off the grid or hydrogen fuel cell bus powered using hydrogen produced via SMR.**

Renewable natural gas offers the second biggest reduction in GHG emissions of any of the technologies analyzed. In fact, renewable natural gas buses produced only 18 to 27 percent of the WTW GHG emissions of even a "zero emission" battery electric powered off the grid or hydrogen fuel cell bus powered using hydrogen produced via SMR. It is only a hybrid hydrogen fuel cell bus powered by hydrogen produced via electrolysis using solar energy that yields lower WTW GHG emissions than those of a renewable natural gas bus. The renewable natural gas assumed in this analysis is recovered from a landfill where, in the best of circumstances, that natural gas would have been flared to the atmosphere, thereby emitting considerable GHG emissions. In the worst case for GHG emissions, landfill methane escapes to the atmosphere, where it is 25 times as potent as CO_2 per the global warming potential for methane used by the CA-GREET model.[25]

Metro CNG Transit Bus

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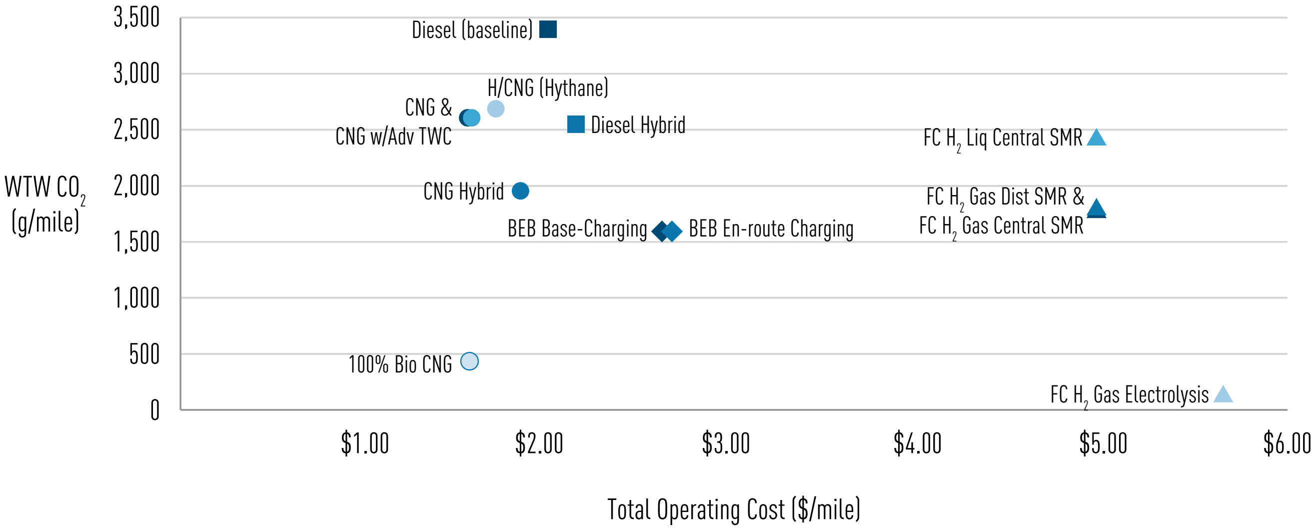
[25] See http://www.ipcc.ch/publications_and_data/ar4/wg1/en/ch2s2-10-2.html

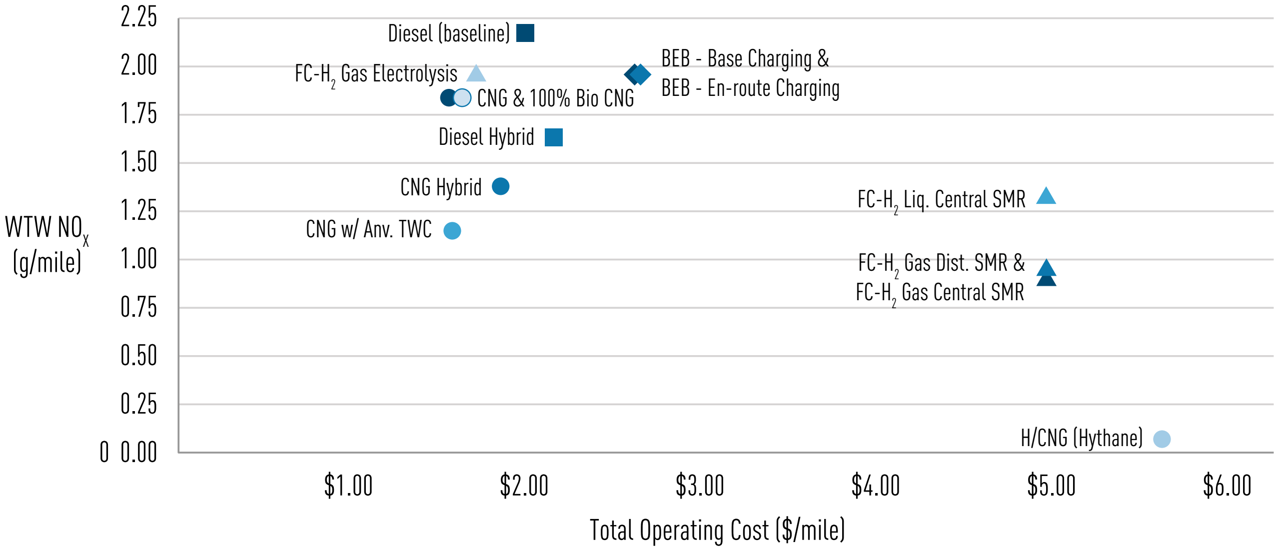
As expected, the zero emission bus technologies, battery electric or hybrid hydrogen fuel cell, show a TTW GHG emissions of zero. Even though these technologies produce no GHG emissions at the vehicle, the production of the hydrogen fuel or electricity to charge the battery electric bus does produce GHG emissions. As discussed previously, the analysis assumes hydrogen production via four different fuel pathways; production of hydrogen gas via centralized SMR, hydrogen gas via distributed SMR, hydrogen liquid via centralized SMR and hydrogen gas via electrolysis. All hydrogen production methods except electrolysis yield the entire WTT production emissions of natural gas (except for CNG compression) plus the added impact of converting that finished natural gas product to compressed hydrogen suitable for fueling a hydrogen fuel cell bus. Figure 1 is a plot of GHG emissions per mile versus total operating cost per mile for each technologies and fuel pathways evaluated. It is clear that a transit bus operating on 100% renewable CNG is the most cost effective option for transit bus operations. While a hybrid hydrogen fuel cell powered by hydrogen produced via electrolysis using solar energy emits the least amount of WTW GHG emissions, it also happens to be the most expensive configuration evaluated.

Figure 1: Cost per Mile vs. WTW CO_2 Emissions



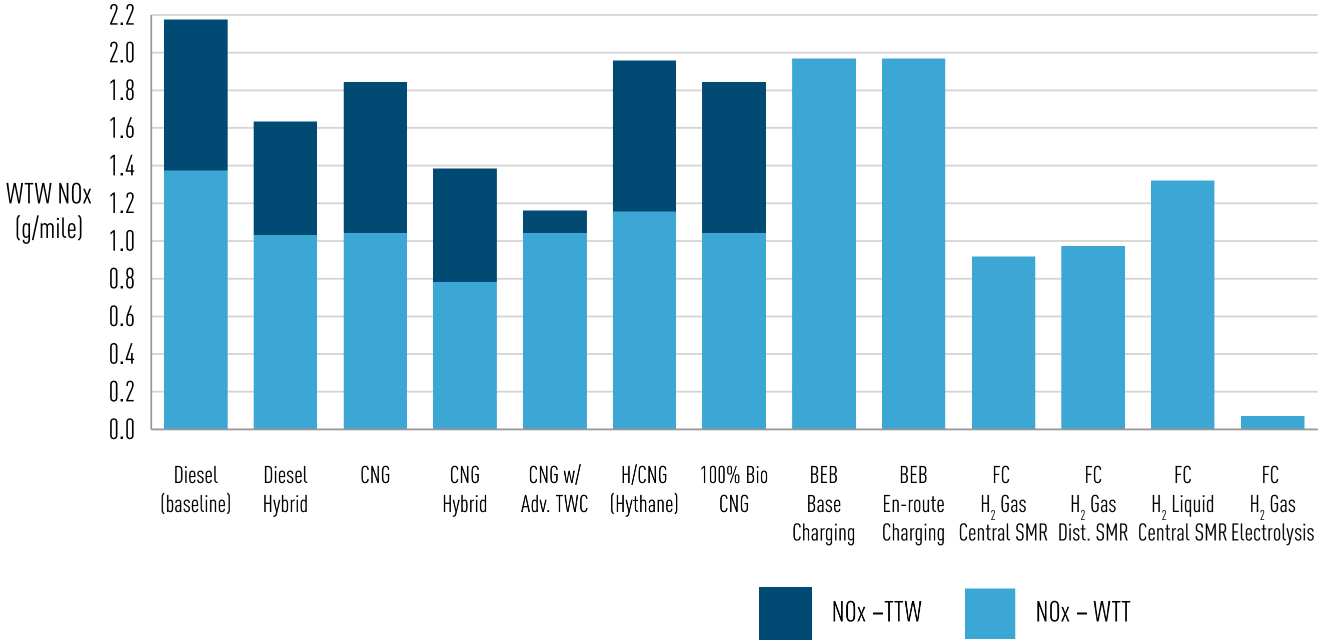
Although not officially a part of the analysis performed for this report, the production of hydrogen or electricity as a fuel also generates WTW NOx emissions. Because NOx is inherently generated in the production process, these technologies are not truly "zero emission" technologies. The figure below is a plot of WTW NOx emissions per mile versus total operating cost per mile. CNG with advanced after-treatment proved to be the most cost effective technology for reducing WTW NOx emissions.

Figure 2: Cost per Mile vs. WTW NOx Emissions



To better understand the full WTW NOx emissions of the various technologies analyzed, Figure 3 displays the total WTW NOx broken down into TTW and WTT. CNG with advanced after-treatment results in total NOx emissions similar to those of the hybrid hydrogen fuel cells analyzed. Further, CNG with advanced after-treatment results in lower WTT NOx emissions than that of a hydrogen fuel cell bus powered by liquid hydrogen produced via central SMR. By way of reminder, Table 9 showed CNG with advanced after-treatment to be amongst the alternative technologies with the lowest total life cycle costs.

Figure 3: WTW NOx emissions of various technologies



The production of CNG, from finding and removing the raw commodity from the ground to processing, transporting and compressing methane on-board a CNG vehicle adds just over one (1) gram per mile to the total WTW NOx emissions, as determined from the CA-GREET model. For diesel fuel the WTT NOx emissions are closer to 1.4 grams per mile. Although the tailpipe or TTW NOx emissions from a hydrogen fuel-cell bus or battery electric bus are zero, the production of hydrogen or electricity is not without emissions. Steam methane reformation from natural gas is the most common and cost effective means of producing hydrogen fuel. Because of this, the WTT NOx emissions for CNG are also included in the WTT NOx emissions for hydrogen. It should be noted that additional WTT NOx emissions are generated during the reformation process and very high compression work that hydrogen fuel undergoes to get it on-board the hydrogen fuel- cell bus. This total process equates to between two and three times the WTT NOx emissions from hydrogen fuel over that of CNG on an energy content basis. This results in total WTT NOx emissions of fuel cell buses using hydrogen produced via SMR being only 7-12 percent less than that of a conventional CNG bus on a grams per mile basis. The WTT NOx emissions from the creation of electricity are even greater than hydrogen production on an energy content basis. The mix of electricity consumed in California used to recharge battery electric buses is 43 percent from natural gas fired power plants, 15 percent from coal-fired power plants, 15 percent from nuclear and 26 percent zero emission electricity generation sources (solar, wind, hydroelectric and geothermal).[26] Even with the great fuel economy for

Even with the great fuel economy for battery electric buses, the WTW NOx per mile driven for a battery electric bus is worse than today's 0.2 g/bhp-hr NOx CNG buses.

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[26] California Air Resources Board, "Detailed California-Modified GREET Pathway for Transportation Fuels: Electricity (Average and Marginal California Mix)." Version 2.1. February 27, 2009. http://www.arb.ca.gov/fuels/lcfs/workgroups/workgroups.htm#pathways.

battery electric buses, the WTW NOx per mile driven for a battery electric bus is worse than today's 0.2 g/bhp-hr NOx CNG buses.

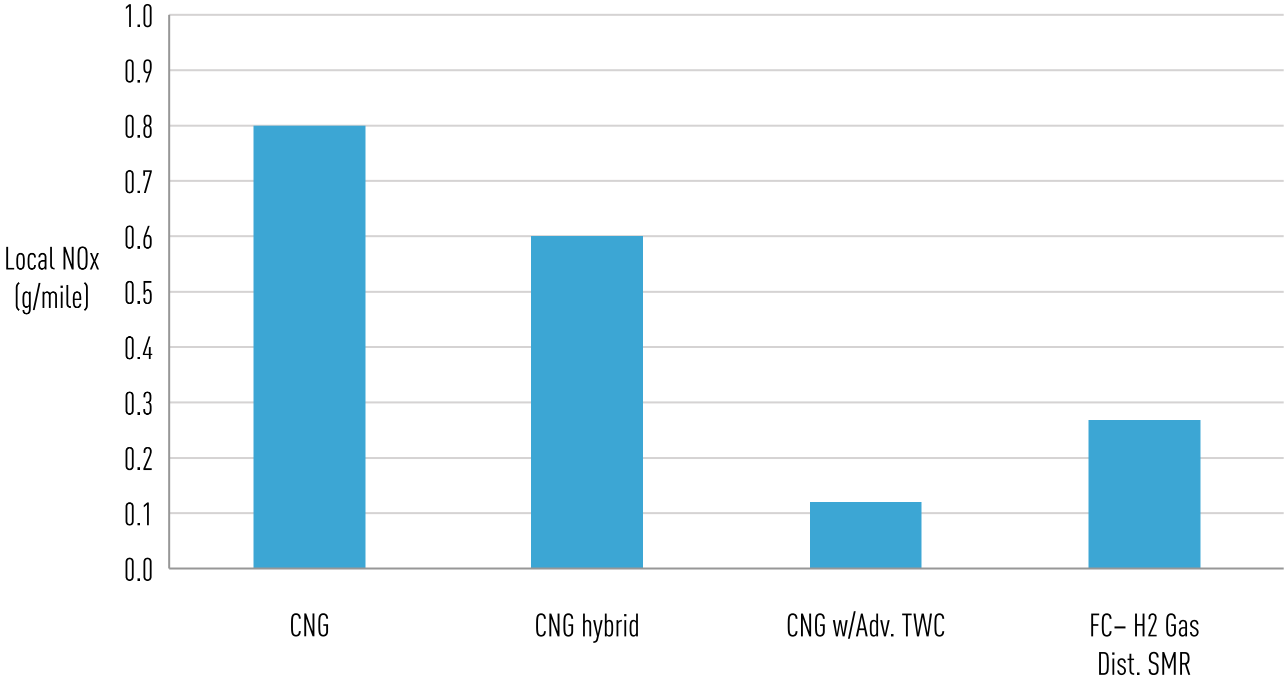
Another aspect often overlooked when evaluating the emissions benefits of hybrid hydrogen fuel cell vehicles is local emissions attributable to the hydrogen production process. For example, producing hydrogen via distributed steam methane reformation is likely to be co-located with the transit bus facility for which the hydrogen fuel is being produced. Therefore, the emissions associated with the SMR would be released to the atmosphere at the same location in which the hydrogen buses are deployed for the purpose of reducing emissions. In the event that hydrogen is produced via centralized SMR, the emissions attributed to the production process would not occur at the site of the transit bus facility but rather at a location some distance away from the facility. This is an important distinction because, while hydrogen fuel cell buses emit zero TTW NOx emissions, fueling these buses via distributed SMR would negate much of the NOx emissions that the buses were intended to eliminate. In order to further evaluate the magnitude of these localized emissions, the NOx emissions corresponding directly from the production of hydrogen were calculated using the CA-GREET model and separated from the rest of the WTT NOx emissions. The production related emissions are generated during the combustion process and released to the atmosphere. The analysis found that hydrogen production via SMR contributes approximately 0.27 grams per mile of NOx directly into the atmosphere at the location of production. In order to understand the significance, these emissions were compared to those emitted locally, i.e. TTW NOx emissions, by a CNG and CNG with advanced after-treatment scenarios.

As shown in the figure below, a hybrid hydrogen fuel cell bus powered by hydrogen produced onsite emits greater than two times the NOx, at the local level, than that emitted by a natural gas bus fitted with advanced after-treatment. Interestingly, a hybrid hydrogen fuel cell bus only emits half of the NOx at a local level as that of a CNG or diesel hybrid bus, but at over twice the cost per mile. While the ZBus regulation promotes the hybrid hydrogen fuel cell transit buses as zero emission vehicles, the production of hydrogen is not without emissions. What has been learned from the analysis is that in certain hydrogen production scenarios, deploying a hybrid hydrogen fuel cell transit bus can have adverse and unintended environmental consequences.

One could argue that producing hydrogen onsite via electrolysis could prevent NOx emissions during the hydrogen production process. While that may be true, the analysis also found this method of hydrogen production led to a hybrid hydrogen fuel cell bus exhibiting the highest total operating cost at $5.65 per mile, more than triple the cost of today's CNG buses.

> **... analysis also found this method of hydrogen production led to a hybrid hydrogen fuel cell bus exhibiting the highest total operating cost per mile at $5.65 per mile, more than triple the cost of today's CNG buses.**

Figure 4: Local NOx emissions from distributed SMR and CNG technologies



Alternative Paths to ZBus Equivalent Reductions

Based on the very nature of the 15 percent zero emission bus regulation purchase requirements, the quantifiable benefit of the ZBus regulation is a 15 percent reduction in TTW criteria pollutants and some reduction in GHG emissions (5 - 10 percent) within a single purchase cycle. The following evaluation describes how each of the technologies discussed previously can be part of a solution that achieves the same quantifiable benefit. Table 11 shows the NOx and GHG reductions, along with the total life cycle cost increase for various technologies or mixes of technologies that achieve or exceed the projected benefits emission of the ZBus regulation's purchase requirements. The percentages shown are compared to baseline 2010 model year diesel. For instance, switching a fleet from 100 percent diesel to one in which 82 percent of the vehicles are powered by conventional CNG using pipeline natural gas and 18 percent using renewable CNG but with advanced after-treatment will result in the same NOx emissions reductions as that same diesel fleet replacing 15 percent of its rolling stock with fuel cell buses. Furthermore, that same fleet would save 21 percent in total life cycle costs compared to a 22 percent increase in total life cycle costs of that fleet complying with the ZBus mandate with fuel cell buses.

There are several other options using various mixes of fuel choices that result in matching the emissions reductions that the current ZBus regulation is meant to achieve, but at considerably less cost than the ZBus regulation. The benefit of each option below has been determined by comparing the emissions for each option to the emissions of a hybrid hydrogen fuel cell bus fueled by hydrogen produced via central SMR.[27]

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[27] A centralized SMR where the SMR is located in a populated area, or an application using distributed SMR, still produces criteria pollutants that affect those in the area and are therefore dirtier than the baseline used when comparing technologies.

Additionally, there are some options that can provide even greater reductions in emissions than the current ZBus regulation projects. For instance, switching from diesel to CNG with 60 percent of all CNG buses using advanced after-treatment and 40 percent of CNG buses using renewable CNG can result in roughly a 50 percent reduction in NOx and GHG emissions while still saving more than 20 percent on the total life cycle cost compared to making no change at all and just running 100 percent 2010 model year diesel powered buses. It should be noted that with renewable CNG being available currently in California at no additional cost, fleets can reduce GHG emissions even more with no increase in operating costs.

Table 11: Technology mix and resulting benefit

Category	Technology Mix	NOx Reductions	GHG Reductions	Cost Increase
Baseline	Baseline Diesel	n/a	n/a	n/a
	CNG	0%	23%	-22%
Regulation	85% Diesel 15% Fuel Cell	15%	7%	22%
	85% CNG 15% Fuel Cell	15%	27%	4%
	85% Diesel 15% Electric	15%	8%	5%
	85% CNG 15% Electric	15%	28%	-14%
Match Regulation at Lower Cost	60% CNG hybrid 40% CNG	15%	35%	-13%
	68% CNG 20% CNG hybrid 12% CNG w/after-treatment	15%	27%	-19%
	82% CNG 18% Renewable CNG w/after-treatment	15%	35%	-22%
Better than Regulation at Lower Cost	60% CNG w/after-treatment 40% Renewable CNG	51%	62%	-21%
	100% CNG w/after-treatment	85%	23%	-21%

Simply switching from diesel to CNG offers significant full life cycle cost savings while considerably reducing GHG emissions, although it would not accomplish the ZBus regulation goal of reducing TTW NOx by 15 percent. However, the findings of the analysis clearly show that other CNG-related technologies, such as advanced after-treatment, renewable CNG and CNG hybrid technology, can also accomplish the emissions benefit of the ZBus regulation while costing the transit agencies millions of dollars less than the ZBus regulation. Most importantly, several of these CNG-related technologies are commercially available and can be implemented today, as opposed to FCEB and battery electric buses that are not at commercial readiness levels commensurate with the needs of the transit industry.

Diesel Path Example (AC Transit spends $70 million more for ZBus)

In order to better see what these numbers really mean, the following sections provide some examples of how this analysis would apply to California transit agencies that are subject to the ZBus regulation. As shown in the results section above, there are several alternative technology choices that could be used in meeting or exceeding the emission reductions that the current ZBus regulation is intended to deliver. AC Transit is the largest diesel path transit agency in California (except for San Francisco Municipal Transportation Agency which has enough electric trolley cars that they already meet their ZBus requirements). AC Transit operates 580 urban diesel buses. For the illustration below, it is assumed that they retire their buses after they accumulated 500,000 miles and/or are 12 years old. It is required by the FTA, if FTA funding was used to purchase the buses, to keep the buses for at least that long. Given this general practice by transit agencies, AC Transit would need to replace, on average, 48 units per year with new buses. Of that annual purchase schedule, the current ZBus requirement would dictate that they must purchase seven (7) to eight (8) zero emission buses each year. The following table summarizes the resulting emission and cost impact if AC Transit were to achieve the goals of the ZBus regulation using alternative technologies.

Table 12: Technology mix and resulting benefit for AC Transit (single purchase cycle)

Technology Mix	Annual NOx Reductions	Annual GHG Reductions	Annual Cost Increase (Savings)
85% Diesel 15% Fuel Cell	0.3 tons	450 metric tons	$900,000
60% CNG hybrid 40% CNG	0.3 tons	2,379 metric tons	($530,000)
82% CNG 18% Renewable CNG w/after-treatment	0.3 tons	2,379 metric tons	($870,000)

Table 12 shows the NOx and GHG reductions, as well as the associated cost increase (or decrease) of implementing several different technology mixes at AC Transit. The emissions and cost are compared as if they were to replace those same older vehicles with new 0.2g NOx diesel urban buses. As a diesel path agency, AC Transit could purchase 85 percent of their new purchases each year with modern diesel engines, around 40 new diesel buses. The other 15 percent would need to be battery electric or hydrogen fuel-cell buses. Assuming that AC Transit complies with the ZBus requirement by purchasing fuel cell buses, after the first year of operations they would reduce their NOx emissions by 0.3 tons and GHG emissions by 490 metric tons. However, they would spend an additional $900,000 in increased capital, fuel, maintenance and other costs for those seven fuel cell buses in that first year of operations, assuming the vehicle capital costs are amortized over the vehicle's 12-year life. In other words, they would spend almost $900,000 more per year, or $10.8 million more amortized over 12 years, to own and operate just seven hydrogen fuel cell buses over their modern diesel equivalent.

Many other options using CNG, CNG with advanced after-treatment, renewable CNG, and CNG hybrids provide AC Transit with the means of reducing both NOx and GHG emissions by amounts equal to, or greater than, the current ZBus regulation at considerably less expense.

Table 13: Technology mix and resulting benefit for AC Transit over 12 years

Technology Mix	Total NOx Reductions	Total GHG Reductions	Total Cost Increase (Savings)
85% Diesel 15% Fuel Cell	21 tons	38,000 metric tons	$70,100,000
85% Diesel 15% Electric	21 tons	43,000 metric tons	$14,600,000
60% CNG hybrid 40% CNG	21 tons	168,000 metric tons	($37,100,000)
82% CNG 18% Renewable CNG w/after-treatment	21 tons	168,000 metric tons	($56,400,000)

Table 13 shows the cumulative benefits of the technology mixes shown in Table 11 for AC Transit. These are the NOx and GHG emission reductions and cost increases (or decreases) over a 12 year period, assuming that each year AC Transit continues to replace about 48 vehicles. As was shown in Table 12, AC Transit would incur a cost increase of almost $900,000 for one year of operation when purchasing seven hydrogen fuel cell buses, and that cost is compounded to $10.8 million for those seven buses over their 12-year useful life. Under the current ZBus mandate, in AC Transit's second year, they would purchase another 48 new buses, with seven being hydrogen fuel cell buses. Over a 12 year period, AC Transit will replace its entire urban bus fleet. Following the current ZBus regulation, they will purchase 493 new 0.2g NOx diesel buses and 87 new hydrogen fuel cell buses. Once the program is fully implemented, the ZBus regulation will be responsible for reducing their total NOx emissions by 15 percent; equaling 21 tons of NOx over the 12 years. The regulation will also be responsible for reducing AC Transit's GHG emissions by 38,000 metric tons over that same 12-year period. Unfortunately, AC Transit will also have spent an additional $70 million to accomplish these reductions—an exorbitant $3.3 million a ton—in contrast to potentially saving $56 million to achieve the same NOx emission reductions and even greater GHG emission reductions. Table 13 shows that the same total NOx reductions can be realized with even greater reductions in GHG emissions for considerably less cost versus if they would have just replaced their fleet with the latest diesel buses. In fact, difference between the low cost option and the high cost option is nearly $130 million. For comparison, AC Transit's operating budget is approximately $320 million. By merely switching from their current path to a 100% CNG path, they could reduce their annual operating budget by 3.6%. It is clear that there are several alternative fuel options other than the agency's current path that would enable AC Transit to save money and generate greater emission reductions.

Alternative-Fuel Path Example (LA Metro spends $308 million more for ZBus)

Like the examples discussed for a diesel path transit agency, such as AC Transit, a similar analysis was done for Los Angeles County Metropolitan Transportation Authority (LA Metro), an alternative-fuel path transit agency. LA Metro has 2,228 full size urban buses and just recently retired the last of their diesel buses. Using the same assumptions as used for AC Transit, LA Metro will replace 186 buses each year.

Table 14 shows the NOx and GHG reductions, as well as the associated cost increase of implementing several different technology mixes shown in the results section for LA Metro. Per the current ZBus regulation, and as an alternative fuel path agency, LA Metro can purchase 85 percent of their new purchases each year with modern natural gas engines, around 158 new natural gas buses. The other 15 percent (28 units annually) would need to be battery electric or hydrogen fuel-cell buses. After the first year, they would reduce their NOx emissions by 1.0 ton and GHG emissions by 970 metric tons. However, they would spend an additional $4.0 million in that first year, amortized over the vehicles' 12-year life. In other words, they would spend almost $4.0 million each year over 12 years, for those 28 hydrogen fuel-cell buses. These additional dollars total an extra $47.5 million to own and operate just 28 hydrogen fuel cell buses instead of their modern natural gas equivalent.

Unfortunately, AC Transit will also have spent an additional $70 million to accomplish these reductions—an exhhorbitant $3.3 million a ton—in contrast to potentially saving $56 million to achieve the same NOx emission reductions and even greater GHG emission reductions.

Many other options using CNG with advanced after-treatment, renewable CNG, and CNG hybrids would provide LA Metro with the means of reducing both NOx and GHG emissions by amounts equal to, or much greater than, the current ZBus regulation at considerably less expense. For instance, LA Metro could purchase 18 percent of all new bus purchases with an advanced after-treatment device and fuel those vehicles with renewable natural gas. This approach would result in similar NOx emission reductions and much greater GHG emission reductions when compared with the ZBus regulation, while costing LA Metro only an additional $30,000 amortized annually over the life of all vehicles purchased in each purchase cycle instead of the $4 million required for ZBus purchases.

Table 14: Technology mix and resulting benefit for LA Metro

Technology Mix	Annual NOx Reductions	Annual GHG Reductions	Annual Cost Increase
85% CNG 15% Fuel Cell	1.0 tons	970 metric tons	$4,000,000
60% CNG hybrid 40% CNG	1.0 tons	3,025 metric tons	$1,330,000
82% CNG 18% Renewable CNG w/after-treatment	1.0 tons	3,025 metric tons	$30,000

Table 15 shows the cumulative benefits of the technology mixes shown in Table 14 for LA Metro. These are the NOx and GHG emission reductions and cost increase over a 12 year period, assuming that each year LA Metro continues to replace 186 vehicles. Table 14 showed a cost increase of almost $4 million in the first year when purchasing 28 hydrogen fuel cell buses, and that equated to $47.5 million for those 28 buses over their 12-year life. In LA Metro's second year, they would purchase another 186 new buses, with 28 being hydrogen fuel cell buses. Over a 12 year period, LA Metro will replace its entire urban bus fleet. Following the current ZBus regulation, they will purchase 1,894 new CNG buses and 334 new hydrogen fuel cell buses. The ZBus regulation will be responsible for reducing their total NOx emissions by 15 percent, equaling 80 tons of NOx over a 12-year period. The regulation will also be responsible for reducing LA Metro's GHG emissions by 75,700 metric tons over that same 12-year period. Unfortunately, they will also have spent an additional $308 million to meet the requirements of the existing regulation—$3.9 million per ton of NOx reduced. Table 15 shows that the same total NOx reductions can be achieved with significantly more reductions in GHG emissions for a fraction of the cost versus the cost of complying with the current ZBus regulation.

Table 15: Technology mix and resulting benefit for LA Metro over 12 years

Technology Mix	Total NOx Reductions	Total GHG Reductions	Total Cost Increase
85% CNG 15% Fuel Cell	80 tons	75,700 metric tons	$308,500,000
85% CNG 15% Electric	81 tons	91,800 metric tons	$95,300,000
60% CNG hybrid 40% CNG	80 tons	236,000 metric tons	$103,400,000
82% CNG 18% Renewable CNG w/after-treatment	81 tons	236,000 metric tons	$2,300,000

> **Unfortunately, they will also have spent an additional $308 million to meet the requirements of the existing regulation—$3.9 million per ton of NOx reduced.**

Conclusion

The objectives of the ZBus mandate are laudable and important for the future of the state of California. It is clear, however, that the costs associated with the current prescriptive regulations remain extremely high with benefits that can be matched or exceeded by less costly alternatives. An optional, performance-based regulation would provide the flexibility needed by cash-strapped transit agencies struggling to maintain services while also minimizing the environmental impact from their operations. Despite continued progress towards the commercial readiness of zero emission bus technology, delays in the development of adequate zero emission bus technology continue to result in the exposure of millions of Californians to avoidable elevated levels of harmful pollutants because of the inability to achieve the reductions intended by the ARB when the regulation was first promulgated. By delaying required changes in transit agency rolling stock, the policy is stifling innovation with other viable alternatives and leaving pollutants in the air that Californians are breathing.

It is clear that there are other options for reducing NOx and GHG emissions in California than requiring electric or fuel cell transit buses. As this analysis and report demonstrates, advanced technologies coupled with the existing 0.2 g/bhp-hr NOx engines can result in equal or greater emission reductions than the current ZBus regulation. The full Fleet Rule for Transit Agencies is a performance based rule that requires emission reductions from the transit agencies, but does not dictate any particular technology or means to accomplish these reductions. It is only the ZBus section of the fleet rules that has a specific requirement of particular technology. This analysis and report shows that similar or better emissions reductions can be realized at considerably less cost to the transit agencies impacted by the ZBus regulation. Further, these benefits can be realized very soon, whereas getting these same benefits from hydrogen fuel-cell buses or battery electric buses is already years behind schedule and could take many, many more years (if ever) to become both operationally practical and cost effective.

Recommendations:

- Implement an emissions reduction performance requirement on new purchases rather than requiring a specific technology; an example being:
  - 15 percent reduction of engine/vehicle NOx totals on all new vehicles.
  - Reduction of engine/vehicle GHG totals on all new vehicles.
- Continue to advance demonstrations and analysis of zero and near zero technologies.
- Modify the California Code of Regulations, Title 13, Sections 2023.1 – 2023.4 to include the option to use near zero technologies that provide equivalent or greater emission reductions than would result from the current regulations.

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