

Issues and Potential Benefits of Natural Gas Vehicles

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Overview

- **Natural gas as a vehicle fuel**
- **Natural gas engine technologies**
- **Advantages and disadvantages of natural gas vehicles**
 - Heavy-duty trucks and buses
 - Light commercial vehicles and passenger cars
 - Three-wheelers and motorcycles
- **Issues**
 - Target vehicle types for NGV conversion/replacement
 - Fuel cost / taxation
 - NGV vs. advanced emission control technology
 - Quality control for natural gas conversions
 - In-use emissions vs. certification data
- **Resources for NGV Program Development**

Natural Gas as a Vehicle Fuel

- **Advantages**
 - Octane > 120 allows high compression ratio in Otto engines
 - Good lean combustion characteristics, clean burning
 - Abundant, underused resource in many developing countries
 - Negligible sulfur / toxic content
 - Less CO₂ / unit of energy than gasoline or diesel
- **Disadvantages**
 - On-board storage - low density requires
 - compressed natural gas (CNG) at 200+ bar
 - liquified natural gas (LNG) at -180 C
 - Cost and weight of on-board storage vessels
 - Cost/complexity/availability of refueling infrastructure
 - Limited availability of engines / vehicles

Natural Gas Engine Technologies

- **Spark ignition / stoichiometric**
 - Direct replacement for gasoline
 - Can use all gasoline emission control technologies
 - electronic fuel injection
 - three-way catalytic converter
 - Dedicated engines can use higher compression ratio
 - increased efficiency and power output
- **Spark ignition / lean burn**
 - Usually heavy-duty diesel-derived engines
- **Compression-ignition / lean burn**
 - “Dual fuel” natural gas engines with diesel pilot ignition
 - Can revert to 100% diesel if required
- **Compression-ignition / high-pressure direct injection**
 - Diesel pilot ignition

Advantages and Disadvantages of Natural Gas Vehicles

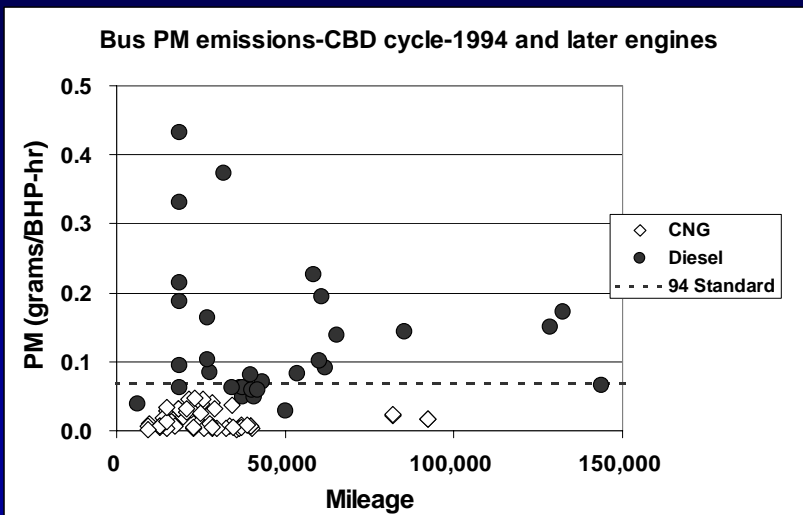
In heavy-duty trucks and buses (replacing diesel)

- **Advantages**
 - Greatly reduce PM and most toxic emissions
 - Little tendency for PM emissions to increase with age and poor maintenance
 - *Potential* reduction in NOx emissions
 - 35-60% for lean-burn
 - 90+% for stoichiometric with three-way catalyst
- **Disadvantages**
 - Higher formaldehyde emissions (requires catalytic converter)
 - NOx emissions are affected by maintenance and driving cycle
 - Power, torque less than highest diesel levels
 - Limited range of engines available

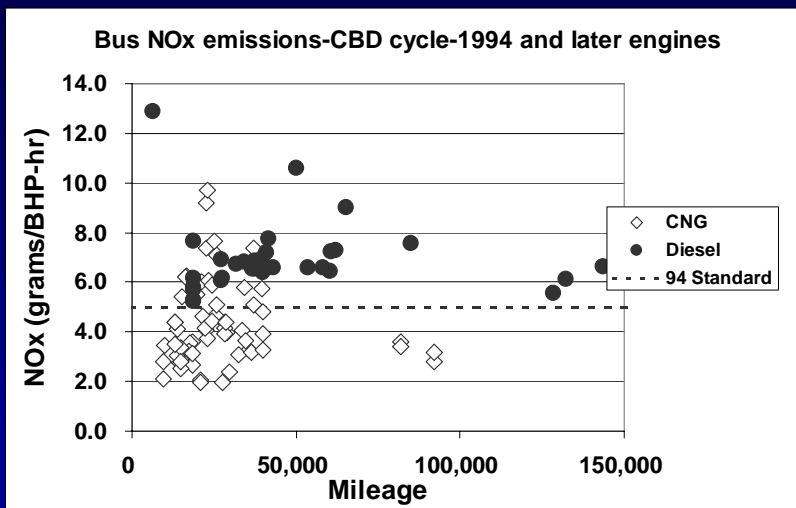
CNG Buses in Delhi



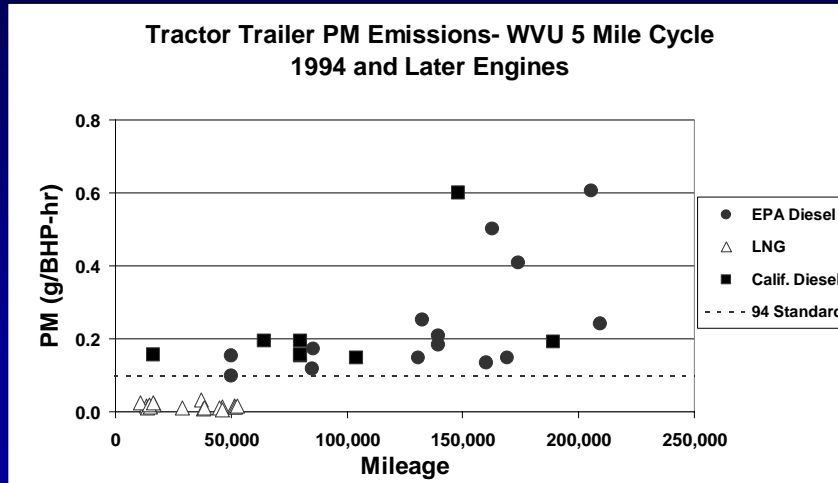
In-Use PM - Diesel vs. CNG Buses



In-Use NOx - Diesel vs. CNG Buses



In-Use PM Emissions -Diesel vs. LNG



Advantages and Disadvantages of Natural Gas Vehicles

In light commercial vehicles and passenger cars

- **Advantages**
 - Greatly-reduced emissions of non-methane HC and toxics
 - Reduced CO emissions esp. cold-start and maximum power
 - don't require or benefit from fuel enrichment for power, starting
 - Better emissions durability
 - *Potential* to reduce NOx emissions
 - Existing gasoline engines can be converted to natural gas
- **Disadvantages**
 - Limited vehicle range
 - Cost of on-board storage
 - Limited selection of OEM vehicles available

Advantages and Disadvantages of Natural Gas Vehicles

In Three-Wheelers and Motorcycles

- **Advantages**

- Greatly reduced NMHC and toxic emissions
- Zero lead emissions
- Reduced CO emissions
- Difficult to adulterate
- Can facilitate switch to four-stroke engines

- **Disadvantages**

- PM reduction in two-strokes depends on technology
- Limited vehicle range
- Limited availability of fuel

CNG Three-Wheelers in Delhi



Issues

- **Target vehicle types for NGV conversion/replacement**
 - Greatest public health benefit comes from substituting NGVs for diesel vehicles
 - buses
 - light-commercial vehicles
 - *but* ease of conversion and fuel pricing usually favor converting gasoline vehicles instead
- **Fuel cost / taxation**
 - Tax policy in most countries favors diesel over gasoline
 - higher tax on gasoline / lower tax or subsidy for diesel
 - Pricing natural gas to limit tax revenue loss relative to gasoline usually makes it uncompetitive with diesel
 - Best solution would be to “internalize” PM health cost in diesel fuel tax (e.g. US\$0.36/liter for Buenos Aires)
 - politically very difficult in most countries
 - Second-best solution may be to cross-subsidize NGV purchase from fuel taxes or other sources

Issues

- **NGV vs. advanced emission control technology**
 - At any given level of emission control technology, NGVs will tend to have lower emissions than diesel or gasoline
 - BUT, as emission controls for conventionally-fueled vehicles get better, the further reductions achievable with natural gas grow less
 - Visible today in California - new light-duty vehicle emission levels are virtually zero. NGVs can achieve even lower emissions, but so what?
 - Conventional vehicles with advanced technology can achieve lower emissions than NGVs with less-advanced technology
 - NGV mixer conversion vs. closed-loop EFI gasoline engine
 - “Green diesel” with catalytic particulate filter and ULSD vs. lean-burn natural gas engine w/o catalytic converter
 - Added costs for fuel storage, etc. are similar regardless of level of emission control achieved - thus, cost-effectiveness declines as the effectiveness of conventional emission controls increases
 - In the long run, NGVs will play a role mostly where abundant natural gas resources make natural gas the lowest-cost transportation fuel

Issues

- **Quality control of NGV conversions**
 - Almost any gasoline vehicle can readily be converted to natural gas
 - Many diesel vehicles can (less readily) be converted as well
 - works best for naturally-aspirated, low-power diesels common in developing nations
 - Safe, durable conversions require quality components and well-trained labor. The resulting costs may not be price-competitive if quality requirements are not effectively enforced
 - Incorrect / unsafe conversion installations are common where correct practices are not effectively enforced
 - U.S. experience
 - Delhi bus program
 - Effective quality control requires either
 - effective third-party inspection of EVERY conversion, before entering service (difficult to establish / enforce) or
 - limiting vehicle conversions to qualified / licensed / authorized facilities only

Faulty CNG Conversions in Delhi Buses



CNG cylinder next to exhaust



No stress loops / piping too rigid / unsupported piping



Issues

- **In-use emissions vs. certification data**
 - Emissions certification values don't necessarily predict in-use emissions
 - Average diesel PM in-use is double applicable emission standards
 - NOx emissions from both diesel and CNG vehicles are affected by interaction between engine control system and driving cycle
 - Use of "defeat devices" in electronically controlled diesel engine
 - Similar pattern observed in some Euro 2 engines
 - Natural gas engines are sensitive to driving cycle
 - light load / high accelerations tend to increase brake-specific NOx
 - Air filter and barometric pressure affect emissions
 - To determine real emission levels, must measure emissions in-use, using a realistic driving cycle(s)
 - on-board emission measurements a viable solution for this
 - Results of in-use measurements often show higher-than-anticipated emissions (for both diesel and natural gas)

In-Use Emission Measurements Mexico City CNG Garbage Trucks

	Bag Emissions g/km			
	CO2	CO	NOx	PM
City Driving				
MAN Stoich 3w Cat	724	3.00	3.31	0.017
Dual Fuel Avg.	500	3.61	6.31	0.144
Dual Fuel w/o FL3	490	3.34	5.45	0.139
Diesel Avg.	558	1.89	7.96	0.169
Garbage Collection				
MAN Stoich 3w Cat	1,674	18.46	7.85	0.019
Dual Fuel Avg.	1,170	6.84	14.61	0.353
Dual Fuel w/o FL3	1,147	6.94	13.93	0.346
Diesel Avg.	1,236	3.27	18.33	0.283



FL3 was a dual-fuel garbage truck with a restricted air filter

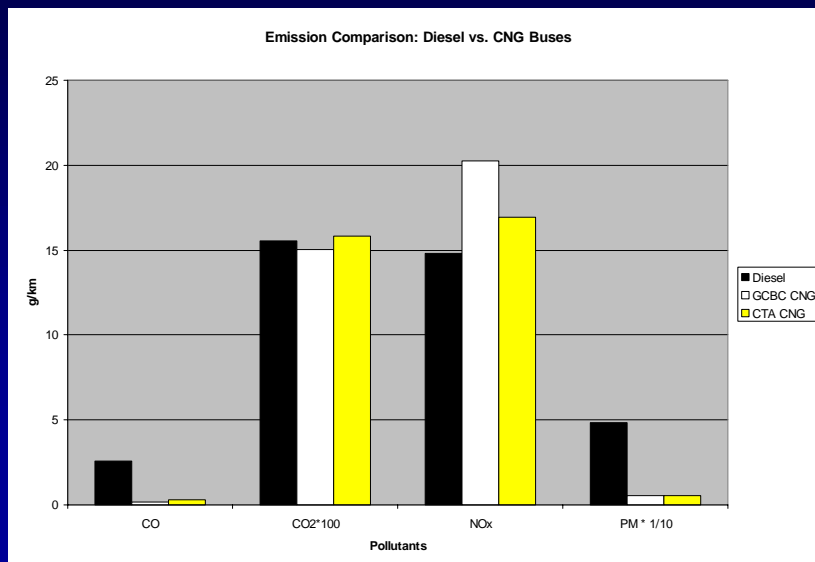
On-Board Emission Measurements

In-Use Emission Measurements Cairo CNG Transit Buses



Heavy-Duty Transient Chassis Dynamometer Emission Measurement Facility in Cairo, Egypt

In-Use Emission Measurements Cairo CNG Transit Buses



Developing an NGV Program

- **Need to involve all stakeholders in planning**
 - example of Clean Cities coalitions
- **Need to get prices and economic incentives right**
- **Need to balance fueling infrastructure with number of vehicles**
 - Better to have too many vehicles than too much infrastructure
 - Capital costs of underused infrastructure may not be recoverable in the fuel price
 - If fuel prices are right, vehicle owners will queue for natural gas fuel
 - Consider an “appointment” system to minimize time wasted in queuing

Resources for NGV Program Development

- **U.S. Department of Energy**
 - Clean Cities Program - www.cities.doe.gov
 - National Renewable Energy Laboratory - www.nrel.gov
- **International Association for Natural Gas Vehicles**
 - www.iangv.org
- **(U.S.) Natural Gas Vehicle Coalition**
 - www.ngvc.org
- **European Natural Gas Vehicle Association**
 - www.engva.org
- **Engine, Fuel, and Emissions Engineering, Inc.**
 - www.efee.com