

**Zero Emissions Bus:  
Could a PZEB Natural Gas  
Hybrid or Plug-in Hybrid  
“Fill the Bill”  
at Much Lower Cost?**

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**ARB ZEB Workshop, Jan. 27, 2006**

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Jan 27, 2006**



# Evolution of Events Since ARB Passed the Transit Rule:

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- Fuel Cell technology has not evolved as fast or as cheap as originally hoped.
- Diesel NOx emissions requirements for urban transit buses have been relaxed for 2007 from 0.2 g to 1.2 g/brk hp-hr.
- Hybrid technology, battery, and natural gas technologies have made significant advances.
- GHG Emissions have emerged as important.



# Current Status of Science and Engineering

- Natural gas HD engines are scheduled to meet 0.2 g NO<sub>x</sub> beginning in 2007.
- Manufacturers are beginning to use lithium ion batteries in hybrid drives.
- Marrying natural gas engines to a hybrid cycle for HD application in an urban bus is completely doable and will result in incrementally lower emissions (NO<sub>x</sub>, PM, & CO<sub>2</sub>) than natural gas alone and much lower than diesel.



## Future Prospects:

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- Natural gas technology is winning the low emissions game with diesel.
- Evolution of “plug-In” hybrids is evolving in HD demonstrations.
- Except for the power plant (IC engine or a fuel cell) the drive line components (batteries, motors, controllers, etc.) of a HD hybrid system are the same between a fuel cell system and an IC engine system.



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**Using the TIAX model for Urban Buses,  
Use of a HD Natural Gas Hybrid Power  
Plant is Predicted to Achieve an  
Environmental “Foot Print” similar to  
that of the Fuel Cell at a much lower cost.**



# Using TIAX Life Cycle Model, projections of cost and emissions can be made for different fuels and technologies.

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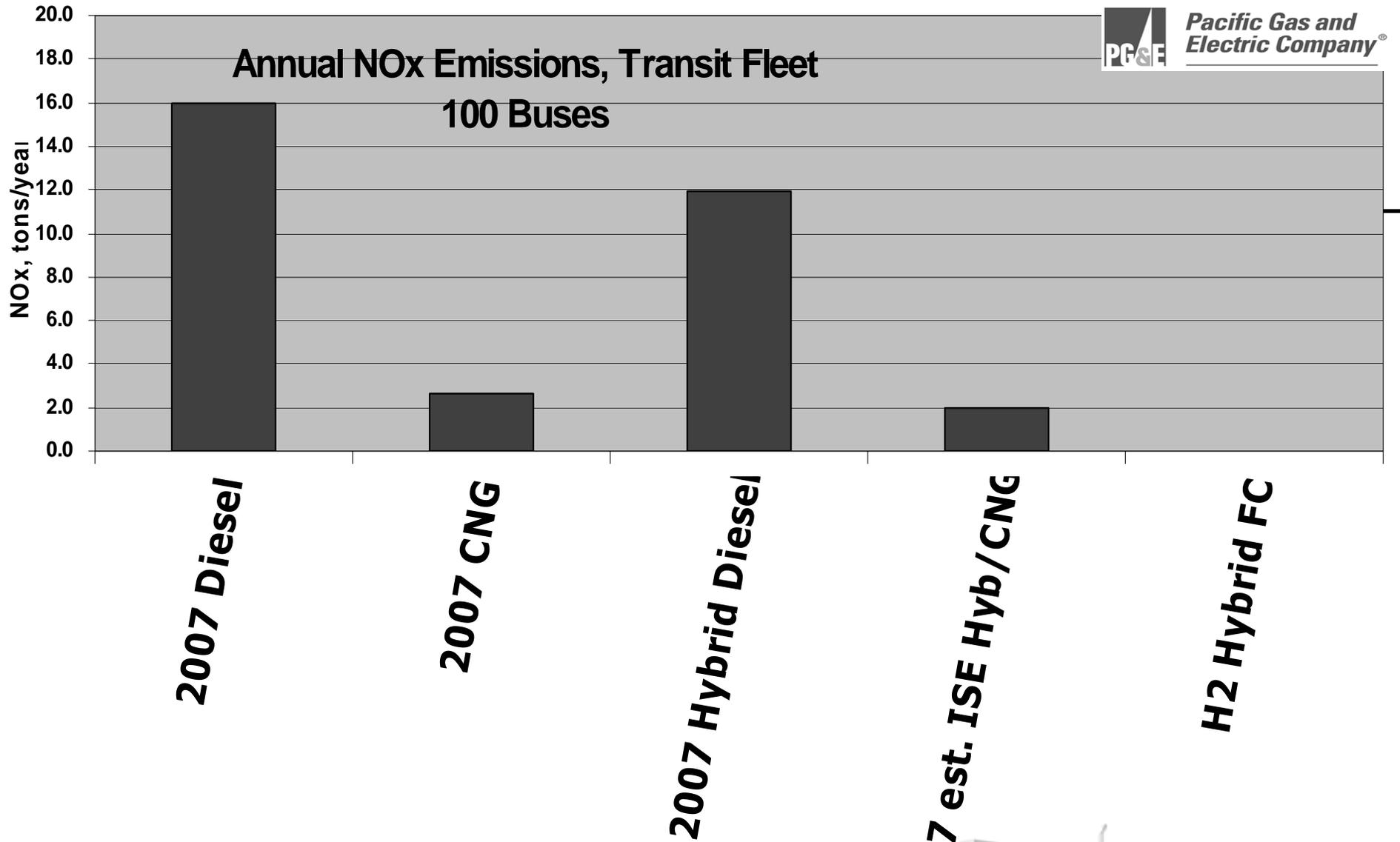
- **DOE funded TIAX to develop an economic model to compare 6 fuels used in transit buses.**
- **TIAX model projects operating costs/mile.**
- **TIAX model predicts relative emissions.**
- **PG&E modified the TIAX model to include future year scenarios with additional fuels.**
- **PG&E preserved original spreadsheet architecture.**



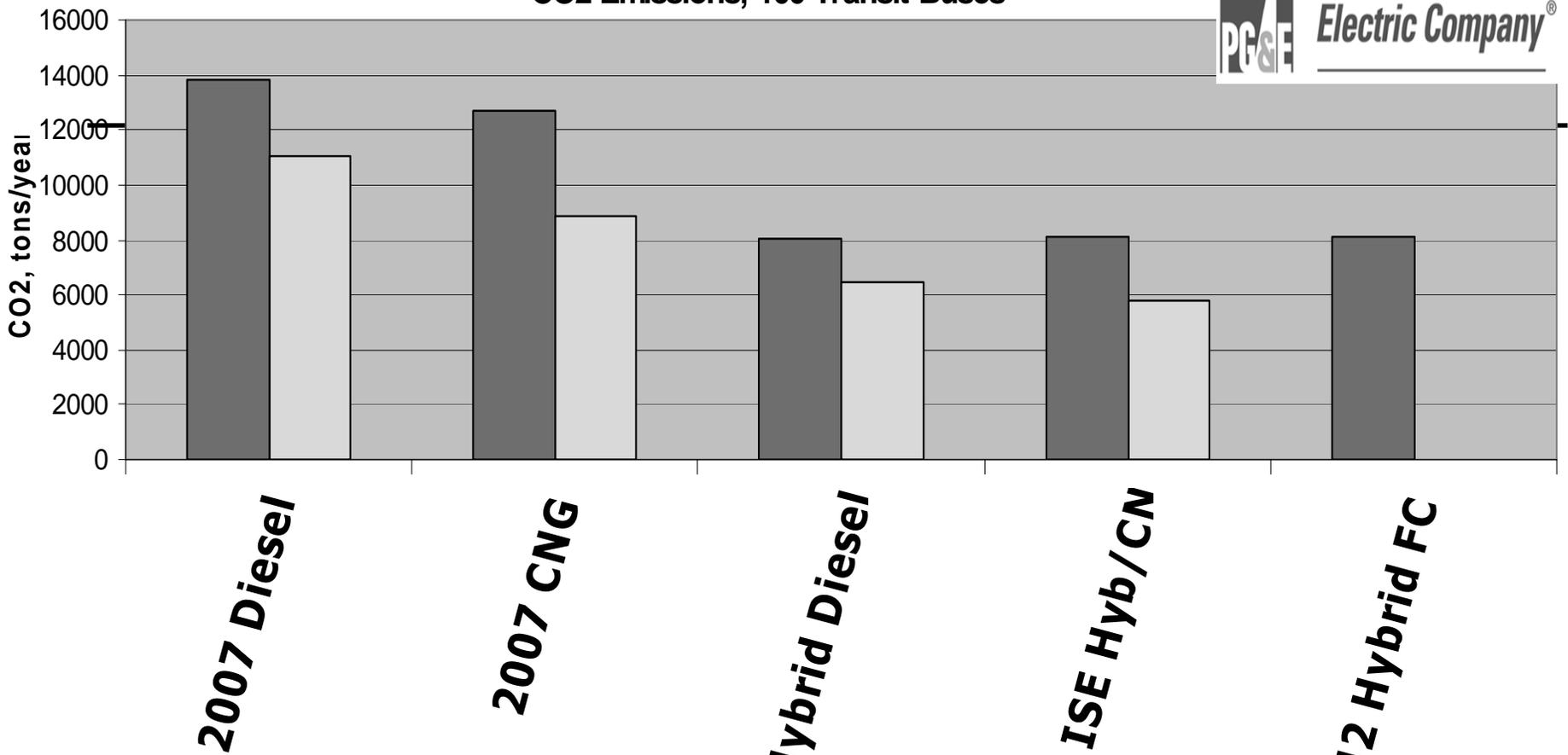
## TIAX Model Input Data:

- **Fuel costs, fuel taxes, fuel energy content (2005-2010)**
- **Vehicle costs with different fuels (2005-2010)**
- **Maintenance costs (routine, HEV brakes, batteries) (2005-2010)**
- **Efficiency, diesel, spark ignition, & hybrid (2005-2010)**
- **Infrastructure (CNG fueling & maintenance, etc.)**
- **Life of vehicles and CNG facilities (13 & 20 years)**
- **Financial discount rate (8%)**
- **Incentives (TFCA, Carl Moyer, Fed. Energy Bill, FTA (buses))**
- **Fleet size, miles per year, avg. MPG**
- **CNG compression costs**



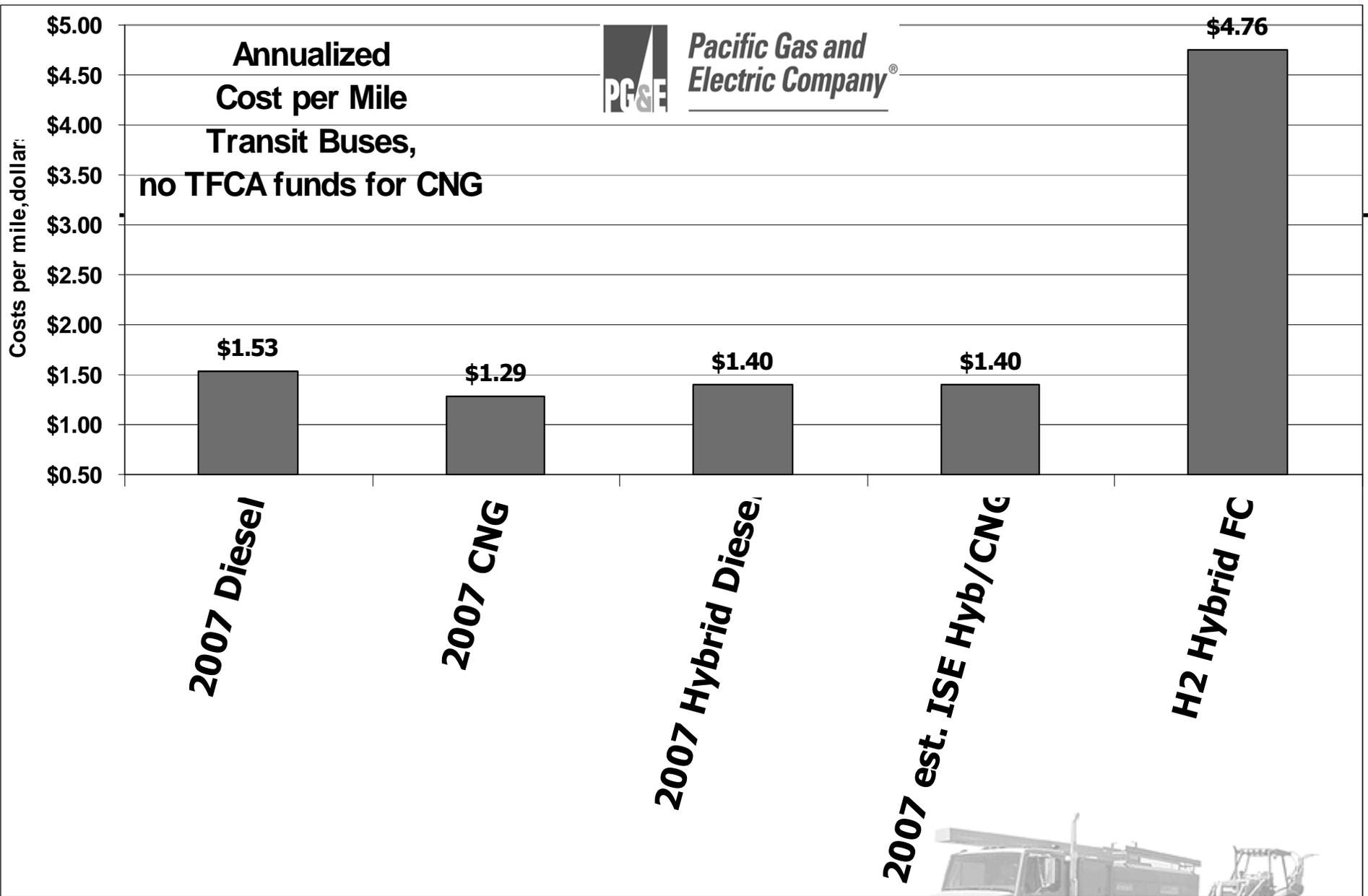


**CO2 Emissions, 100 Transit Buses**



■ Well head to Wheel  
□ Tailpipe





# Conclusions:

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- **Environmental Footprint of CNG Hybrid Buses Approaches that of the Hydrogen Fuel Cell. CO<sub>2</sub> emissions look the same on a wellhead to wheel basis**
- **Up-front cost of NG hybrid bus is projected to be a fraction, <20%, of that a H<sub>2</sub> Fuel Cell powered bus.**
- **Life cycle costs of NG hybrid bus is projected to be 30% of the H<sub>2</sub> Fuel Cell powered bus.**
- **Components for a NG hybrid are available off-the-shelf.**
- **Life cycle costs and emissions of a plug-in NG Hybrid Bus should be even more favorable: analysis is pending.**
- **Can PZEBs used to satisfy the original intent of the Transit Rule?**

