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Fuel Cell Bus Life Cycle Cost Model

Current Base Case & Future Cost Scenarios

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Outline

- Life Cycle Cost Model
  - What is included?
  - Required Inputs (assumptions)
  - Format of Results
- Sources for “Base Case” Assumptions
- Base Case Results
- “Best Case” Future Cost Scenario

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Project Overview

This analysis was conducted using a spread-sheet based Life Cycle Cost Model developed for the Volpe National Transportation Systems Center by M.J. Bradley & Associates. The model is designed to allow side-by-side analysis of multiple bus/technology types that operate on a range of liquid and gaseous fuels. The model will support on-going fuel cell bus work at the Department of Transportation.

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Life Cycle Cost Model

- Developed specifically for this project
- Designed to be flexible
  - Can analyze multiple liquid & gaseous fuels
  - All major cost assumptions can be modified by user
  - Can analyze buses with different useful lives
  - Technology-specific cost elements included
- Up to 8 bus/technology types can be analyzed side-by-side

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Included Cost Elements

- Capital Costs:
  - Bus purchase
  - Infrastructure (fuel station, depot modifications, special tools)
- Annual Operating costs:
  - Bus operator labor
  - Bus maintenance
  - Periodic bus overhaul
  - Training
  - Fuel station/depot systems O&M

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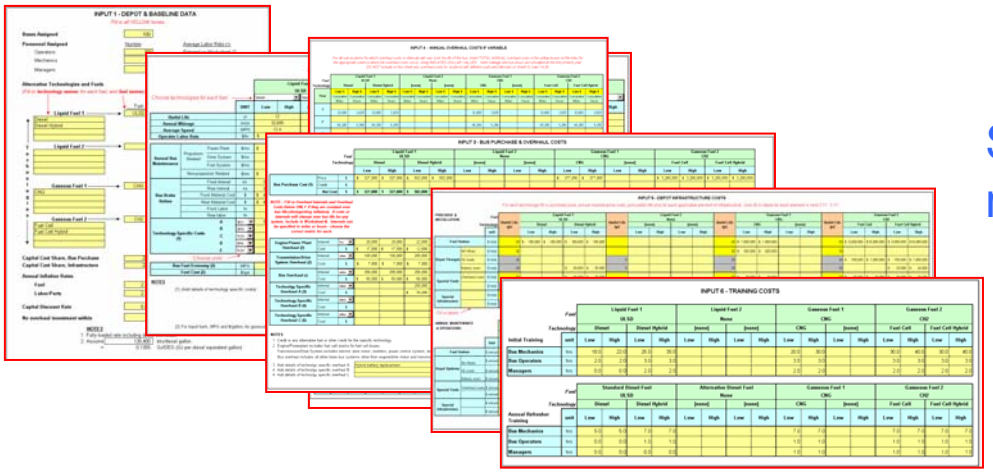
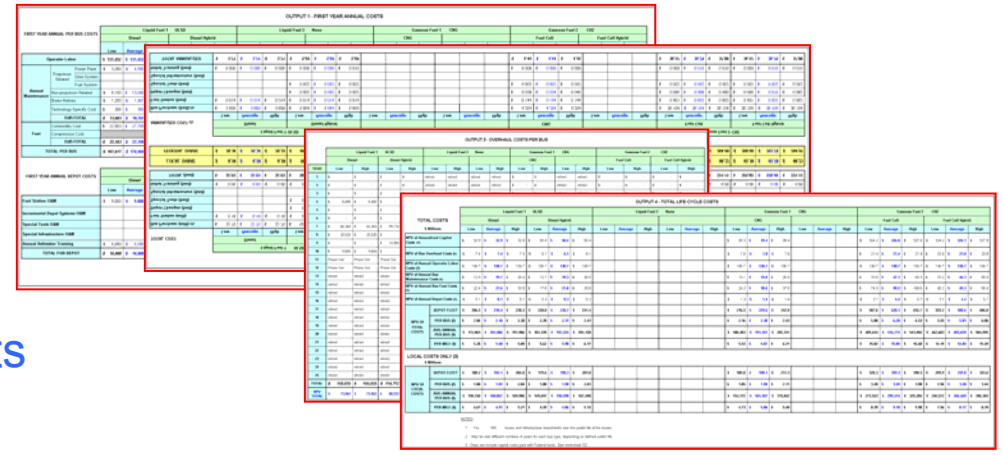
Spread Sheet Tool



Six Input worksheets for required assumptions

- Number of buses
- Labor rates
- Bus purchase costs, etc



Four output worksheets for results of calculations

- First year operating costs
- Capital costs
- Overhaul Costs
- NPV of total life cycle costs

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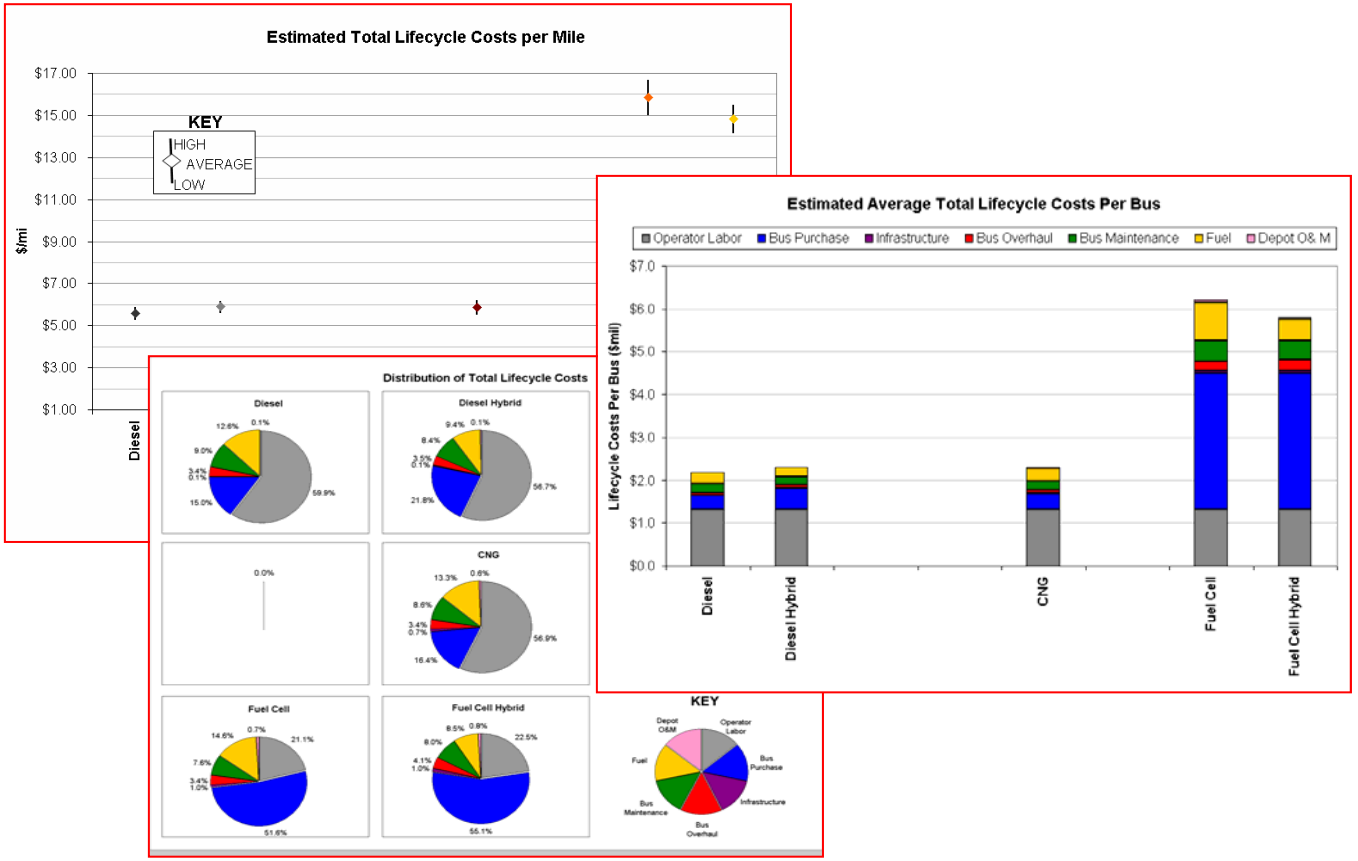
Graphical Results



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Required Inputs

Operating Assumptions

- Number of buses
- Annual Mileage per bus
- Average In-service Speed (mph)

Financial Assumptions

- Bus Useful Life (yrs)
- Discount Rate (%)
- Federal Capital Cost Share (%)
- Annual Inflation Rate (%)
- Fuel Costs ($/gal, $/GJ)
- Labor Rates ($/hr)

Technology-Specific Assumptions

- $/mi maintenance costs
- Fuel Economy (MPDEG)
- Bus overhaul interval & cost
- Bus purchase costs
- Fuel station purchase costs
- Depot modification costs
- Purchase cost of special tools
- Training (hrs/employee)

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Fuel Cell Bus "Base Case"

- Intended to evaluate current costs for Fuel Cell buses compared to other bus propulsion options
  - Fuel cell technology is in its infancy while other technologies are mature (diesel, CNG) and maturing (hybrid)
- Five bus/technology options were analyzed, which use three different fuels
  - Diesel Fuel: Diesel & Diesel Hybrid buses
  - Natural Gas: CNG buses
  - Hydrogen: Fuel Cell & Fuel Cell Hybrid buses
- For all technologies, the base vehicle is assumed to be a 40-ft urban transit bus

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Technology Details

	Diesel	Diesel Hybrid	CNG	Fuel Cell	Fuel Cell Hybrid
Power Plant	Diesel Engine	Diesel Engine	Natural Gas Engine	PEM Fuel Cell Engine	PEM Fuel Cell Engine
Drive System	5-speed automatic transmission	Generator Electric motor Power electronics Energy storage	5-speed automatic transmission	Electric motor Power electronics	Electric motor Power electronics Energy storage
Fuel System	Diesel tank	Diesel tank	3,600 psi CNG storage	5,000 psi $C\text{-}H_2$ Storage	5,000 psi $C\text{-}H_2$ Storage

All other bus systems assumed to be the same for all bus types

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Sources of Base Case Assumptions

SOURCE	ASSUMPTIONS
USDOT National Transit Database	Annual Bus Mileage Average in-service speed Average in-service Fuel Economy (Diesel, CNG)
USDOE Clean Cities Alternative Fuels Price Report (Mar 2007)	Diesel Fuel cost CNG fuel cost
2006 APTA Transit Vehicle Database	Bus Purchase costs (Diesel, CNG, Diesel Hybrid)
30-yr T-Bill & TIPS Yields	Discount rate Annual inflation rate
USDOE Transit Costs 1.0 Model	CNG fuel station & depot infrastructure costs
NREL Advanced Vehicle Testing Activity reports - 1 Fuel Cell bus report - 2 Fuel Cell Hybrid bus reports - 2 Natural Gas bus reports - 2 Diesel Hybrid bus reports	$/mi maintenance costs (all bus types) Hydrogen fuel cost Fuel Cell & Fuel Cell Hybrid bus purchase cost Hydrogen fuel station purchase costs Fuel Cell & Fuel Cell Hybrid bus fuel economy
Manufacturer literature/discussion with transit maintenance managers	Overhaul costs Overhaul intervals

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NREL Data – Fuel Cell Buses

		Unit	AC TRANSIT 4/06 - 11/06 *40-ft Fuel Cell Hybrid* *40-ft Diesel*		VTA 11/04 - 7/06 *40-ft Fuel Cell* *40-ft Diesel*		SUNLINE 1/06 - 11/06 *40-ft Fuel Cell Hybrid* *40-ft CNG*	
Capital ($ mill)	H2 Fuel Station Installation	total	not reported		$ 0.64		not reported	
	H2 Depot Modifications	total	$ 1.50		$ 4.40		$ 0.05	
	Fuel Cell Bus Purchase	ea	$ 3.20		$ 3.50		$ 3.10	
Fuel Economy	Duty Cycle	MPH	11.6		14.5		13.0	
	Fuel Cell Fuel Economy	mi/kg	5.50		3.12		7.3	
		MPDEG	6.22		3.52		8.28	
	Diesel Fuel Economy	MPG	4.00		3.98		CNG = 3.32	
Fuel Cost	Hydrogen Cost	$/kg	$ 8.00		$ 9.06		$ 4.26	
	Diesel Cost	$/gal	$ 2.30		$ 2.07		CNG = $1.10	
Maintenance Cost			***Fuel Cell***	***Diesel***	***Fuel Cell***	***Diesel***	***Fuel Cell***	***CNG***
	PMI	$/mi	$ 0.15	$ 0.08	$ 0.61	$ 0.09	$ 0.05	$ 0.08
	Powerplant	$/mi	$ 0.01	$ 0.10	$ 1.54	$ 0.16	$ 0.11	$ 0.05
	Drive System	$/mi	$ 0.04	$ -	$ 0.36	$ 0.02	$ 0.06	$ -
	Fuel System	$/mi	$ 0.01	$ 0.02	$ 0.48	$ 0.02	$ -	$ 0.01
	TOTAL PROPULSION	$/mi	$ 0.06	$ 0.12	$ 2.38	$ 0.20	$ 0.17	$ 0.06
	NON-PROPULSION	$/mi	$ 0.54	$ 0.23	$ 1.17	$ 0.34	$ 0.27	$ 0.19
	TOTAL	$/mi	$ 0.60	$ 0.35	$ 3.55	$ 0.54	$ 0.44	$ 0.25

SOURCES			
	AC Transit	NREL/TP-560-41041	March 2007
	VTA	NREL/TP-560-40615	November 2006
	Sunline	NREL/TP-560-41001	February 2007

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NREL Data – NG & Hybrid Buses

		Unit	DART 6/98 - 1/00 *40-ft LNG* *40-ft Diesel*		WMATA 9/01 - 9/04 *40-ft CNG* *40-ft Diesel*		KC METRO 4/05 - 3/06 *60-ft Diesel Hybrid* *60-ft Diesel*		NYCT 10/04 - 8/05 *40-ft Diesel Hybrid* *40-ft CNG*	
Capital ($ mill)	Diesel Fuel Station	total	not reported		not reported		not reported		not reported	
	NG Fuel Station	total	$ 7.50		$ 4.00		NA		$ 7.40	
	Hybrid Depot Modifications	total	NA		NA		None		/depot - 2 battery conditi	
	NG Depot Modifications	total	incl in NG fuel station		$ 11.60		NA		not reported	
	Hybrid Bus Purchase	ea	NA		NA		$ 0.645		not reported	
	NG Bus Purchase	ea	not reported		$ 0.34		NA		not reported	
Fuel Economy	Duty Cycle	MPH	13.7 - 14.4		11.6		11.6 - 12.4		6.2 - 6.5	
	Hybrid Fuel Economy	MPG	NA		NA		3.17		3.2	
	NG Fuel Economy	MPDEG	2.70		2.32 - 2.39		NA		1.7	
	Diesel Fuel Economy	MPG	3.80		2.84		2.50		2.30 - 2.40	
Fuel Cost	NG Cost	$/DEG	$ 0.82		$ 1.50		NA		$ 1.74	
	Diesel Cost	$/gal	$ 0.90		$ 1.33		$ 1.98		$ 1.78	
Maintenance Cost			*LNG*	*Diesel*	*CNG*	*Diesel*	*Hybrid*	*Diesel*	*Hybrid*	*CNG*
	PMI	$/mi	$ 0.07	$ 0.07	$0.12-$0.14	$ 0.17	$ 0.05	$ 0.05	$ 0.17	$ 0.12
	Powerplant	$/mi	$ 0.08	$ 0.06	$0.11-$0.12	$ 0.11	$ 0.11	$ 0.12	$ 0.17	$ 0.25
	Drive System	$/mi	$ 0.02	$ 0.01	$0.01-$0.03	$ 0.04	$ 0.01	$ -	$ 0.18	$ 0.04
	Fuel System	$/mi	$ 0.01	$ 0.01	$0.01-$0.02	$ 0.01	$ 0.01	$ -	$ 0.02	$ 0.06
	TOTAL PROPULSION	$/mi	$ 0.11	$ 0.08	$0.13-$0.17	$ 0.16	$ 0.13	$ 0.12	$ 0.37	$ 0.35
	NON-PROPULSION	$/mi	$ 0.29	$ 0.45	$0.39-$0.41	$ 0.43	$ 0.31	$ 0.34	$ 0.86	$ 0.94
	TOTAL	$/mi	$ 0.40	$ 0.53	$0.52-$0.58	$ 0.59	$ 0.44	$ 0.46	$ 1.23	$ 1.29

SOURCES

DART	NREL, *Dart's LNG Bus Fleet Final Results*, October 2000
WMATA	NREL/TP-540-37626 April 2006
KC Metro	NREL/TP-540-40585 December 2006
NYCT	NREL/TP-540-40125 November 2006

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Major Base Case Assumptions

	Diesel	Diesel Hybrid	CNG	Fuel Cell	FC Hybrid
Number of Buses	100				
Useful Life	12 years				
Annual Mileage	32,600				
Average Speed	12.4 MPH				
Labor Cost	$50/hr				
Fuel Costs	Diesel = $2.63/gal		CNG = $2.17/DEG		H2 = $6.70/kg
Maintenance ($/mi)	$0.55	$0.56	$0.56	$1.40	$1.40
Fuel Economy (MPDEG)	3.2	4.0	2.4	2.8	5.1
Bus Purchase	$327,000	$502,000	$377,000	$3.2 mill	$3.2 mill
Fuel Station Purchase	$180,000	$180,000	$1.8 mill	$3.5-$7.0 mill	$1.7-$4.0 mill
Other Infrastructure	$0	$45,000	$450,000	$875,000	$895,000

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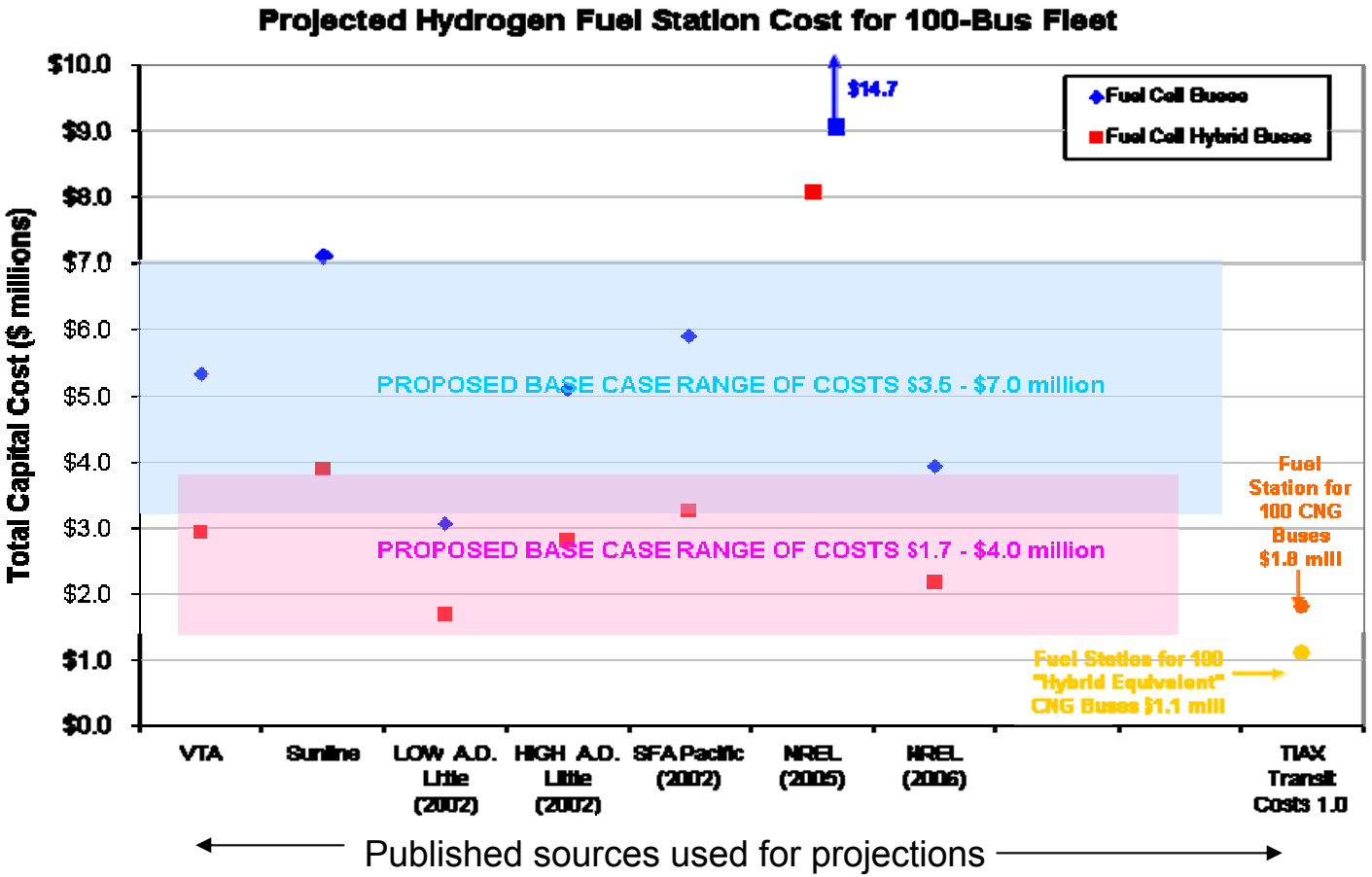
Hydrogen Fuel Station Costs



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Base Case – First Year Costs

PER BUS COSTS

			Average Cost per Bus				
			Diesel	Diesel Hybrid	CNG	Fuel Cell	Fuel Cell Hybrid
Operator Labor			$ 131,452	$ 131,452	$ 131,452	$ 131,452	$ 131,452
Annual Maintenance	Propulsion Related	Power Plant	$ 4,890	$ 5,216	$ 5,216	$ 32,600	$ 32,600
		Drive System	$ -	$ -	$ -	$ -	$ -
		Fuel System	$ -	$ -	$ -	$ -	$ -
	Non-propulsion Related		$ 13,040	$ 13,040	$ 13,040	$ 13,040	$ 13,040
	Brake Relines		$ 1,487	$ 850	$ 1,652	$ 1,749	$ 929
	Technology-Specific Cost		$ 350	$ 350	$ -	$ -	$ -
	SUB-TOTAL		*$ 19,767*	*$ 19,456*	*$ 19,908*	*$ 47,389*	*$ 46,569*
Fuel			$ 27,769	$ 21,922	$ 30,778	$ 90,991	$ 49,580
TOTAL PER BUS			$ 178,988	$ 172,829	$ 182,138	$ 269,832	$ 227,601

ADDITIONAL DEPOT COSTS

	Average Cost per Depot				
	Diesel	Diesel Hybrid	CNG	Fuel Cell	Fuel Cell Hybrid
Fuel Station O&M	$ 9,000	$ 9,000	$ 90,000	$ 262,500	$ 142,500
Incremental Depot Systems Maintenance	$ -	$ 1,000	$ 21,250	$ 42,500	$ 43,500
Maintenance of Special Tools	$ -	$ 1,250	$ 1,250	$ 1,250	$ 1,250
Maintenance of Special Infrastructure	$ -	$ -	$ -	$ -	$ -
Annual Refresher Training	$ 5,000	$ 22,000	$ 24,250	$ 24,250	$ 24,250
TOTAL FOR DEPOT	$ 14,000	$ 33,250	$ 136,750	$ 330,500	$ 211,500

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Base Case – Capital Costs

	Average Cost for 100 Buses				
	Diesel	Diesel Hybrid	CNG	Fuel Cell	Fuel Cell Hybrid
Bus Purchase (mil$) (1)	$ 32.70	$ 50.20	$ 37.70	$ 320.00	$ 320.00
Fuel Station (mil$)	$ 0.18	$ 0.18	$ 1.80	$ 5.25	$ 2.85
Depot Changes ($mil)	$ -	$ 0.02	$ 0.43	$ 0.85	$ 0.87
Special Tools ($mil)	$ -	$ 0.03	$ 0.03	$ 0.03	$ 0.03
Special Infrastructure ($mil)	$ -	$ -	$ -	$ -	$ -
Initial Training ($mil)	$ 0.05	$ 0.08	$ 0.07	$ 0.08	$ 0.08
TOTAL ($mil)	**$ 32.93**	**$ 50.50**	**$ 40.02**	**$ 326.21**	**$ 323.83**

LOCAL SHARE	$ 6.59	$ 10.10	$ 8.00	$ 65.24	$ 64.77
FEDERAL SHARE	$ 26.34	$ 40.40	$ 32.02	$ 260.97	$ 259.06

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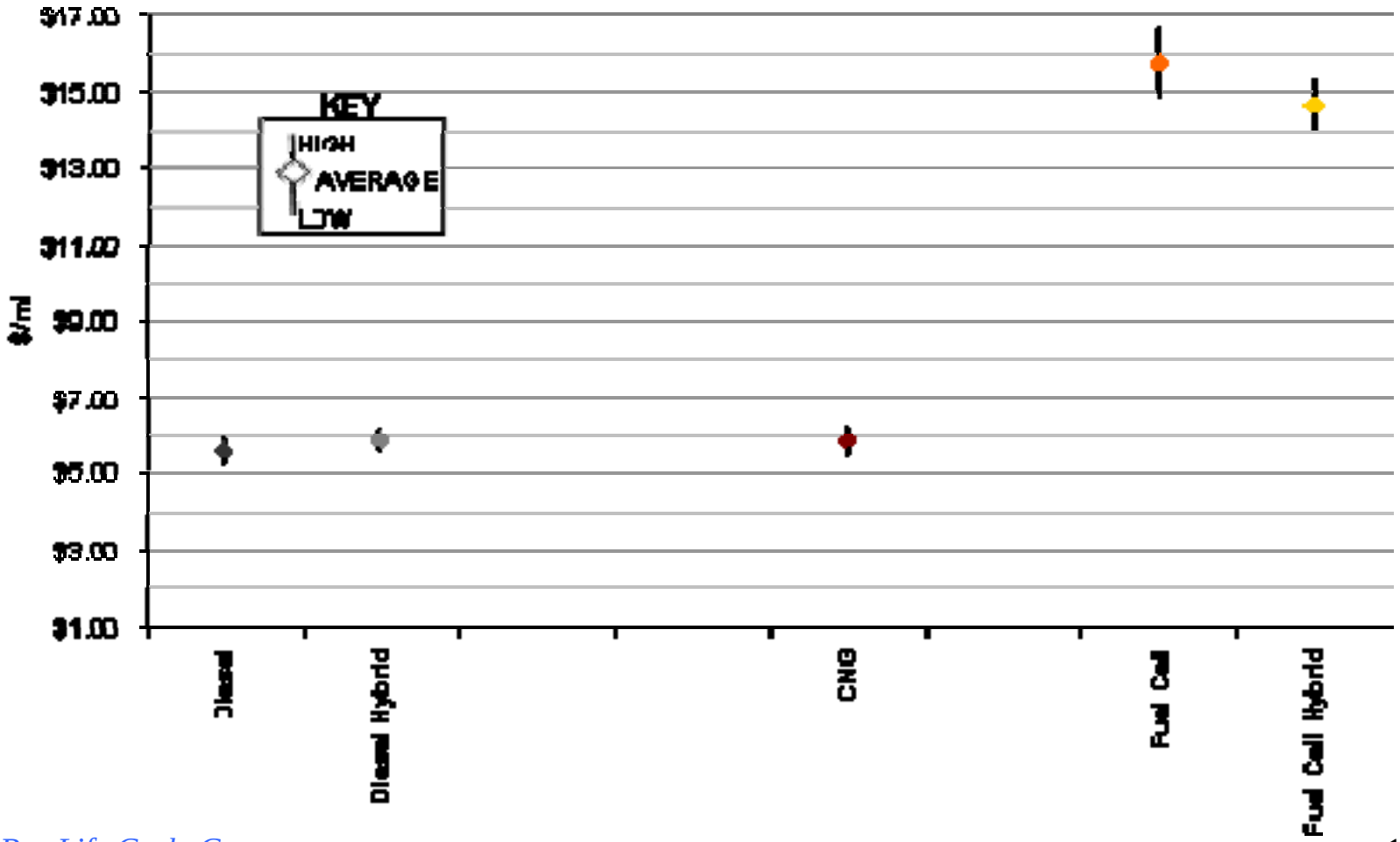
Base Case – Total Life Cycle $/mi



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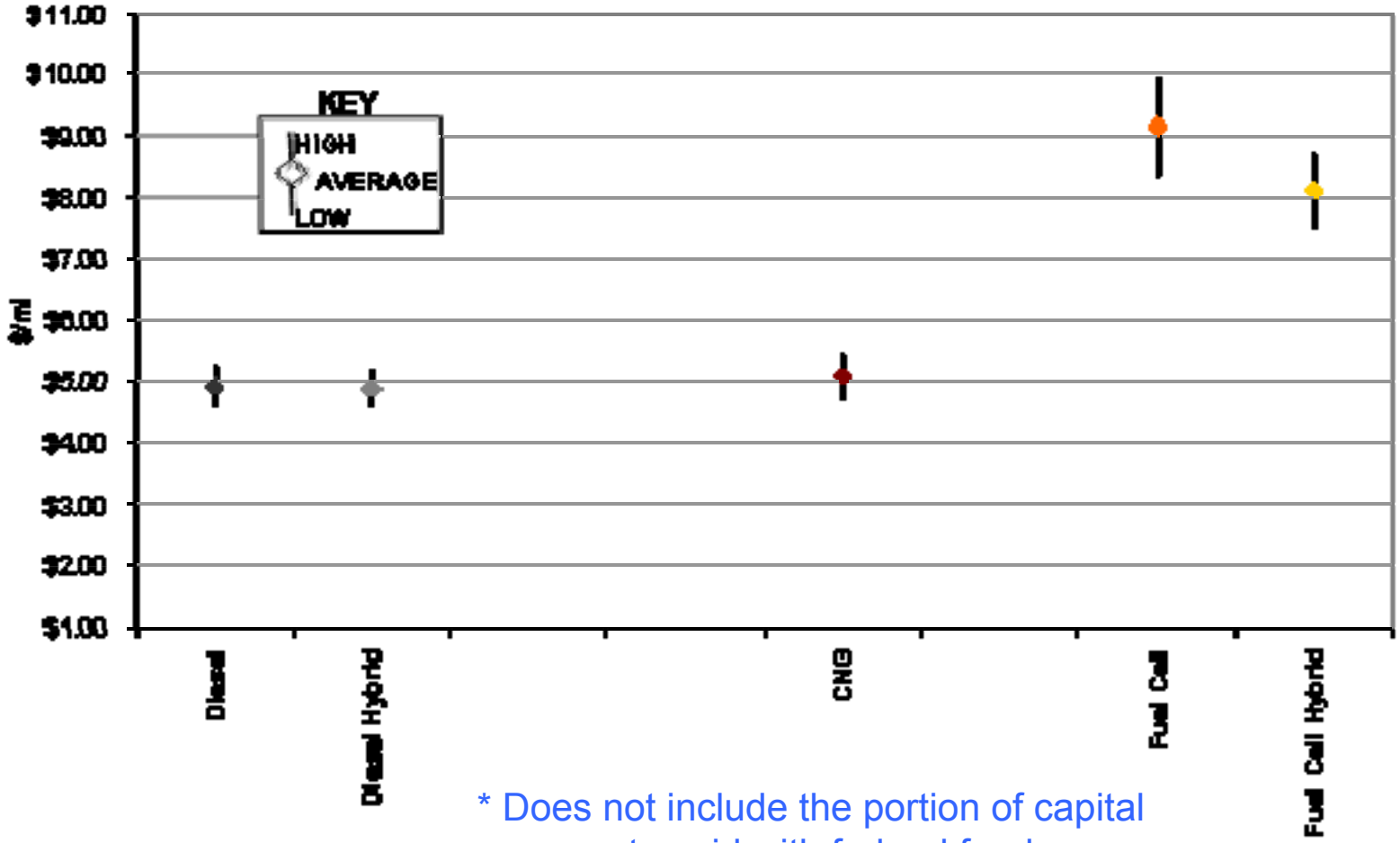
Base Case – Local* Life Cycle $/mi



* Does not include the portion of capital costs paid with federal funds

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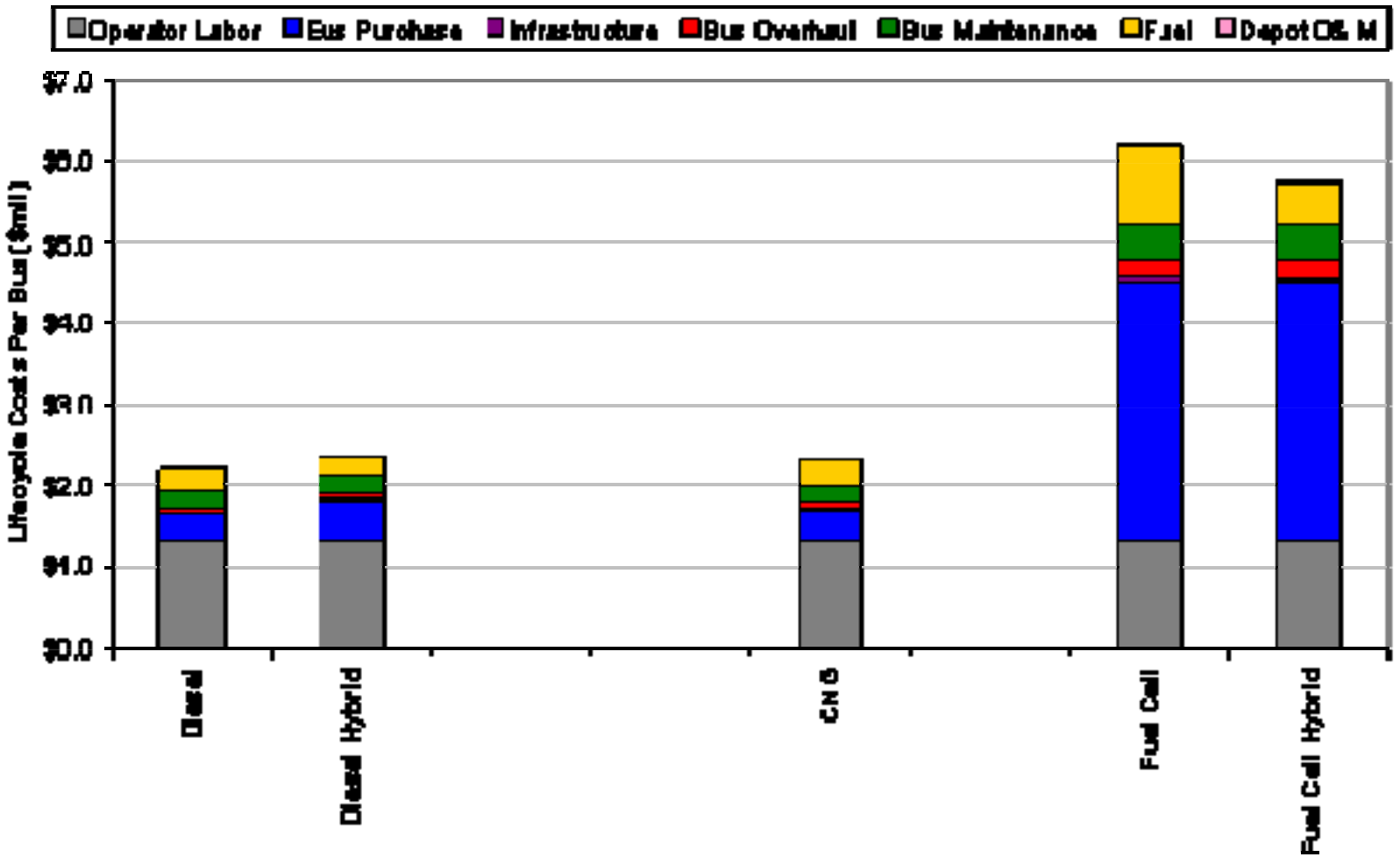
Base Case – Total Life Cycle $/bus



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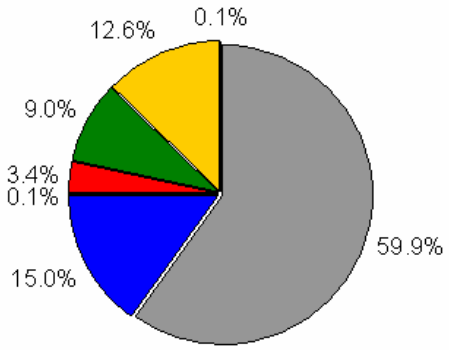
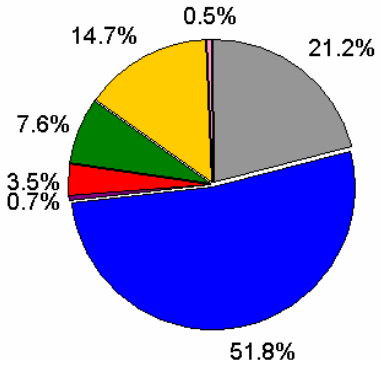
Base Case – Cost Distribution

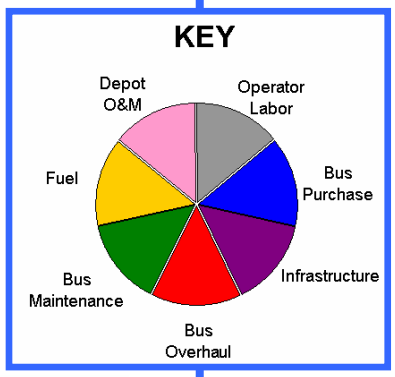
TOTAL LIFE CYCLE COSTS

Diesel



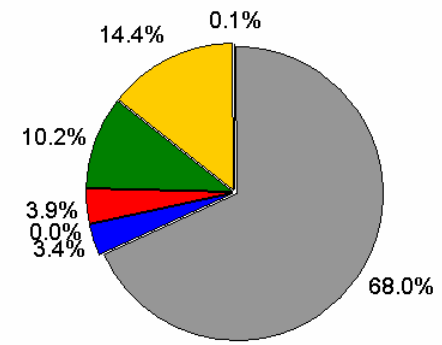
Fuel Cell



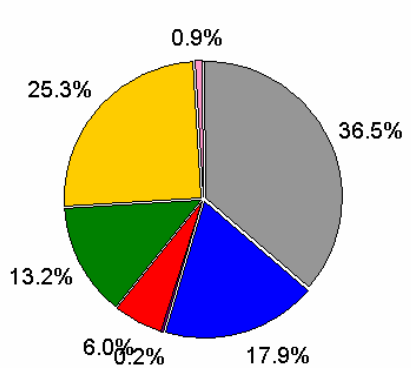


LOCAL LIFE CYCLE COSTS

Diesel



Fuel Cell



The distribution of costs for CNG and Diesel Hybrid buses is similar to Diesel buses

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Base Case Summary

- Total Life Cycle Costs for Fuel Cell buses are currently 3 times higher than costs for Diesel, CNG, and Diesel Hybrid buses
  - If only local costs are included, current fuel cell buses still cost 60-90% more per mile to operate than Diesel buses
- All cost elements are higher for Fuel Cell buses
  - Capital costs 10x higher
  - Overhaul costs 3x higher
  - Annual Maintenance costs 2x higher
  - Fuel Costs 2 -3 x higher
- Capital amortization accounts for 15% of total costs with Diesel buses, but over 50% with Fuel Cell buses

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Near Term Future Costs – "Best Case"

- The "Best Case" Scenario is based on meeting FTA's near-term National Fuel Cell Bus performance objectives...
  - Bus Purchase Cost ≤ 5x Diesel bus = $1.6 mill
  - Fuel Cell stack durability 20,000 - 30,000 hrs
  - Double fuel economy of Diesel bus = 6.4 MPDEG

  ... and DOE's 2015 goal for hydrogen cost

  - <$3/kg (untaxed) in 2005 dollars = $3.39/DEG

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Other "Best Case" Assumptions

- To meet fuel economy goal, assume that Fuel Cell buses must use hybrid propulsion
- Other Major assumptions:

$/mi propulsion maintenance costs ≤ 2x Diesel

= $0.20 - $0.40/mi

Hydrogen fuel station cost ≤ 2x cost of similar capacity CNG station

= $1.8 mill (for station approx ½ size of CNG station)

Fuel cell stack replacement cost ½ of base case cost

= $50,000

Hybrid battery replacement cost 2/3 of base case cost

=$20,000

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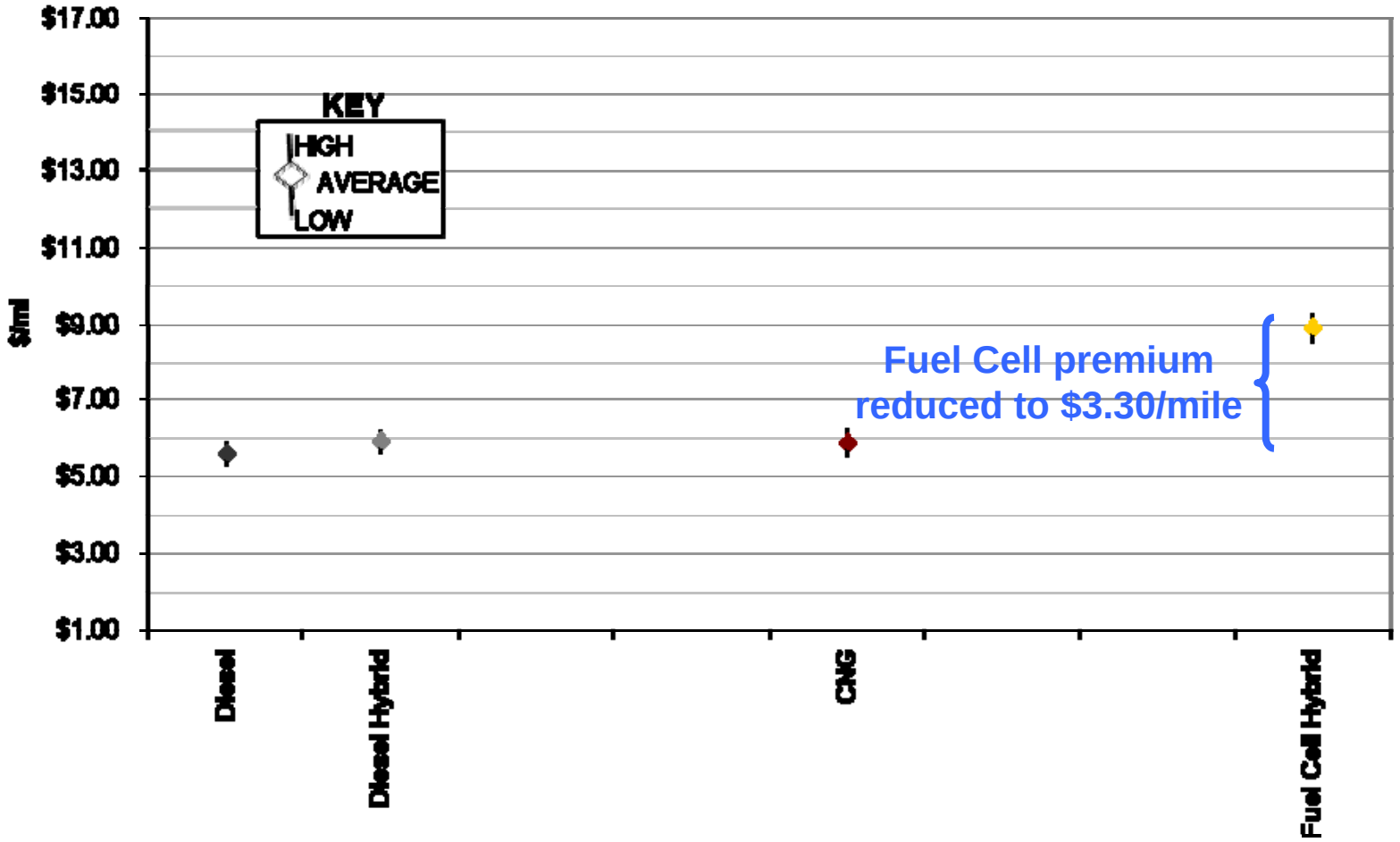
Best Case – Total Life Cycle $/mi



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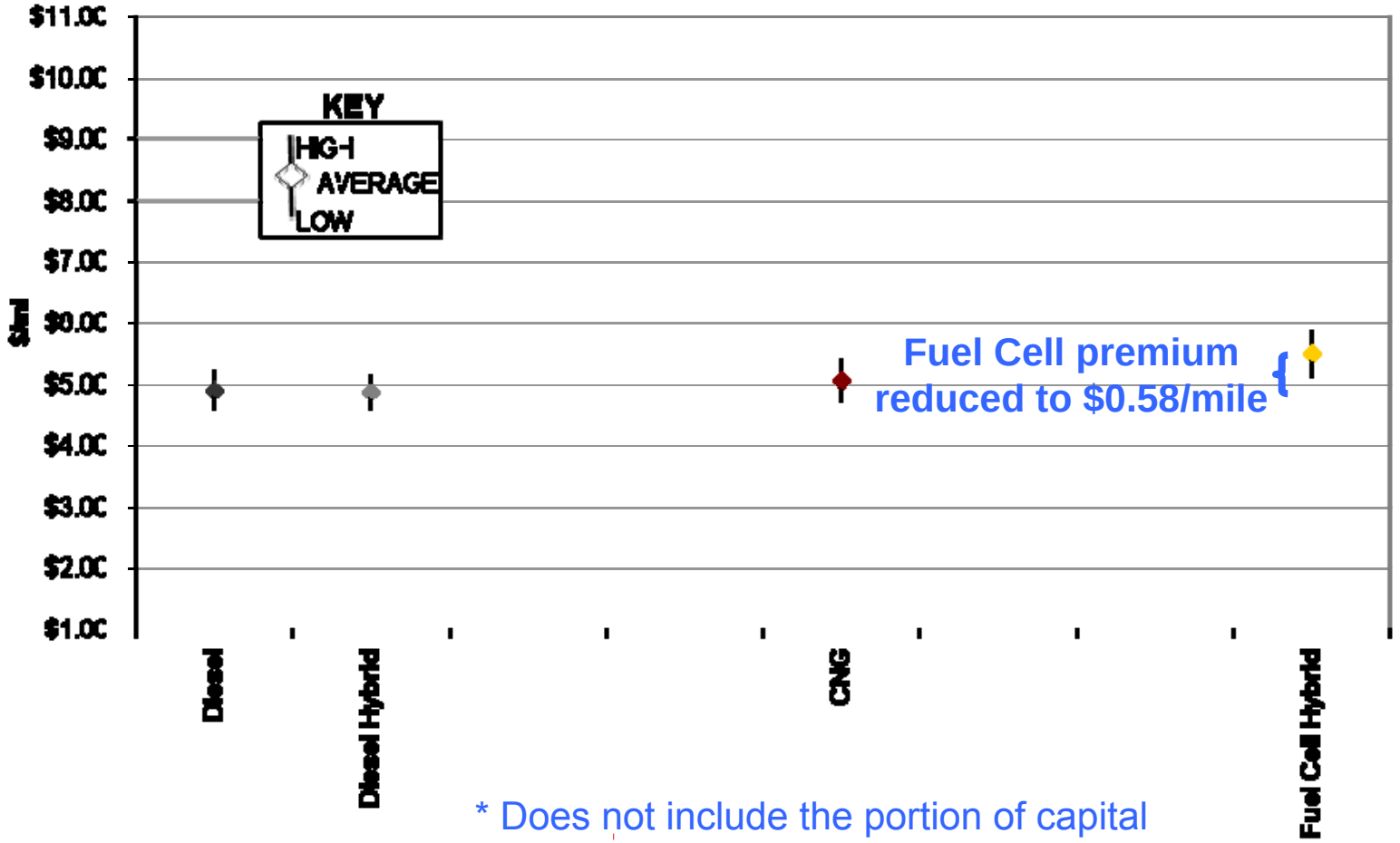
Best Case – Local* Life Cycle $/mi



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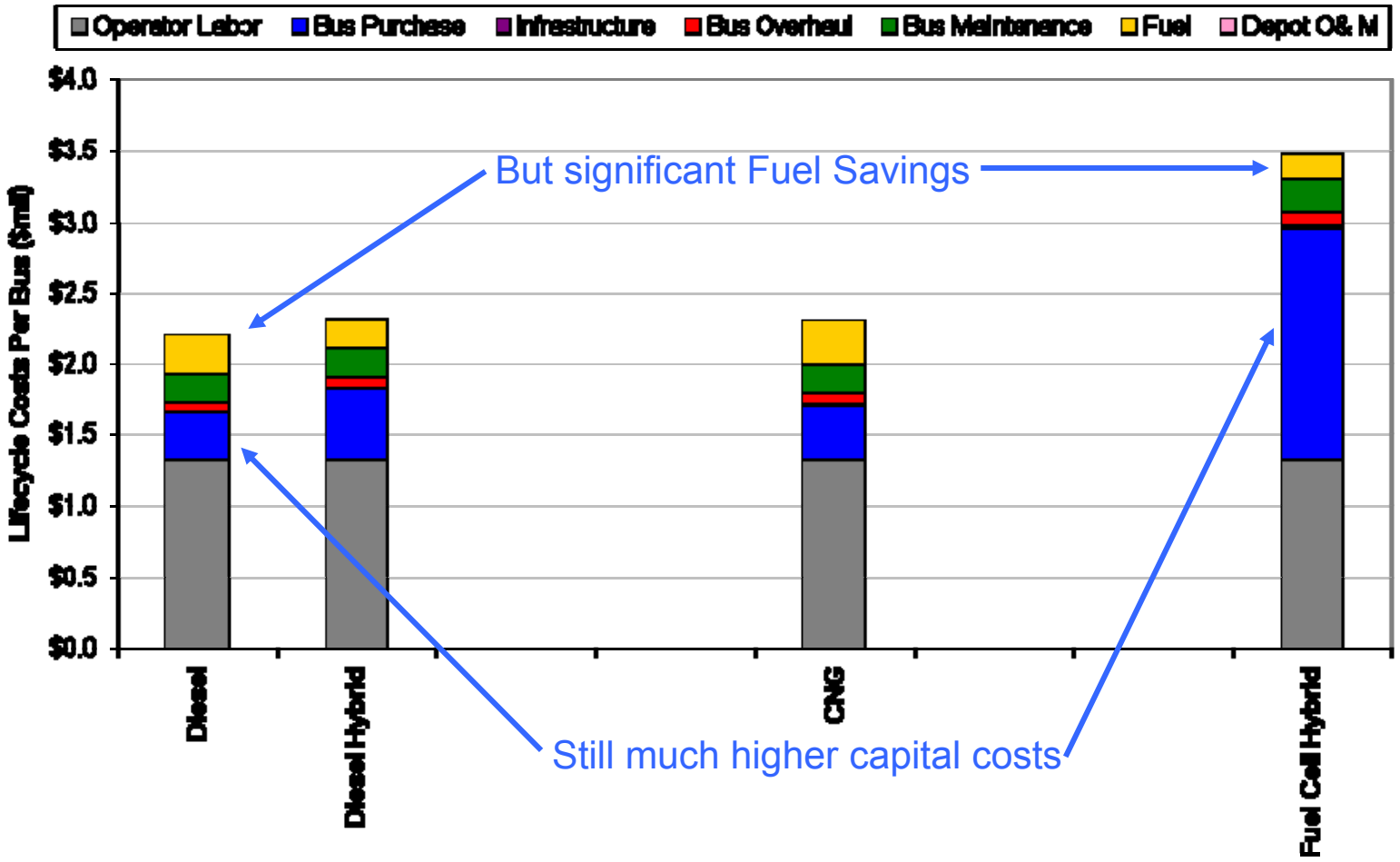
Best Case – Total Life Cycle $/bus



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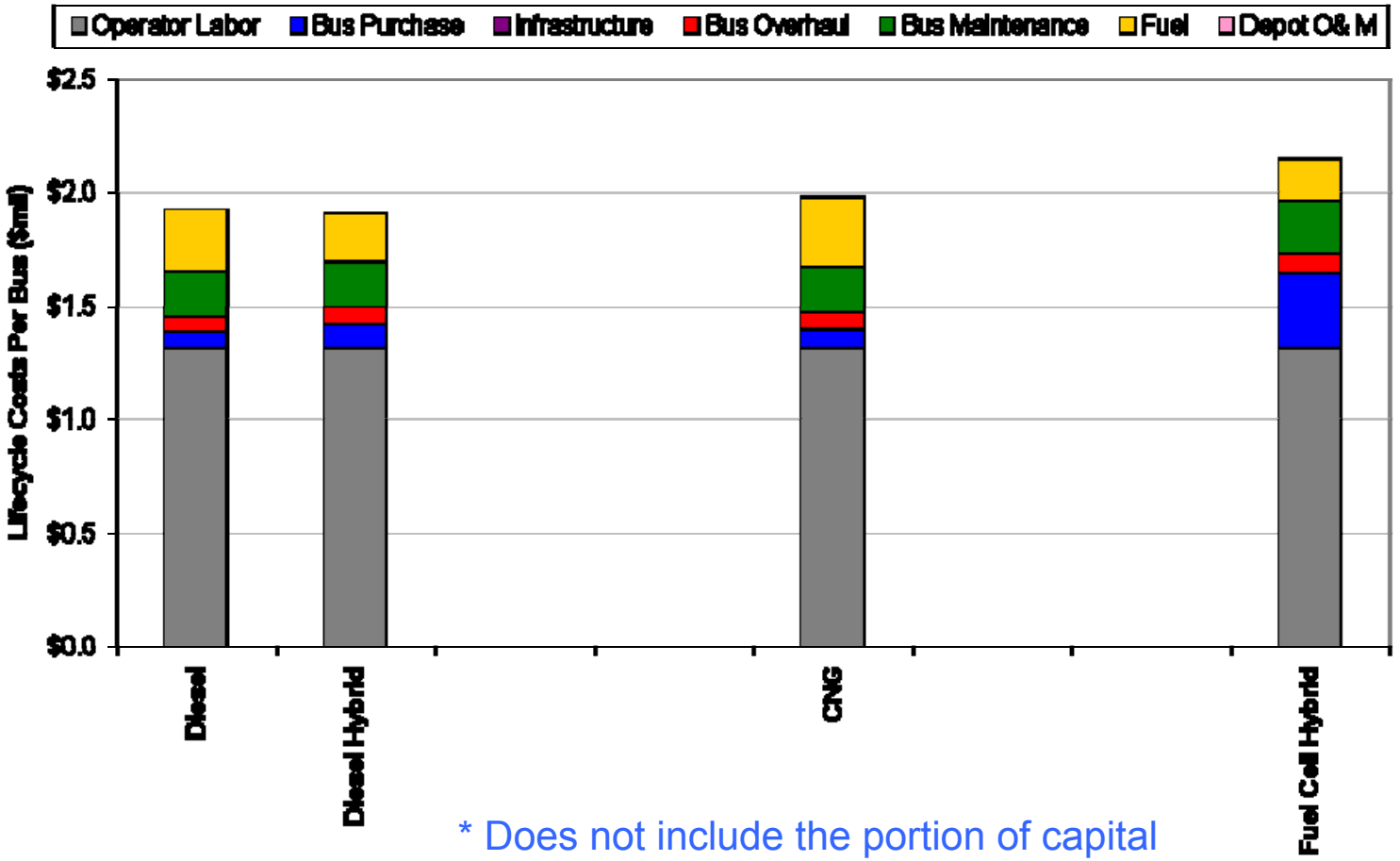
Best Case – Local* Life Cycle $/bus



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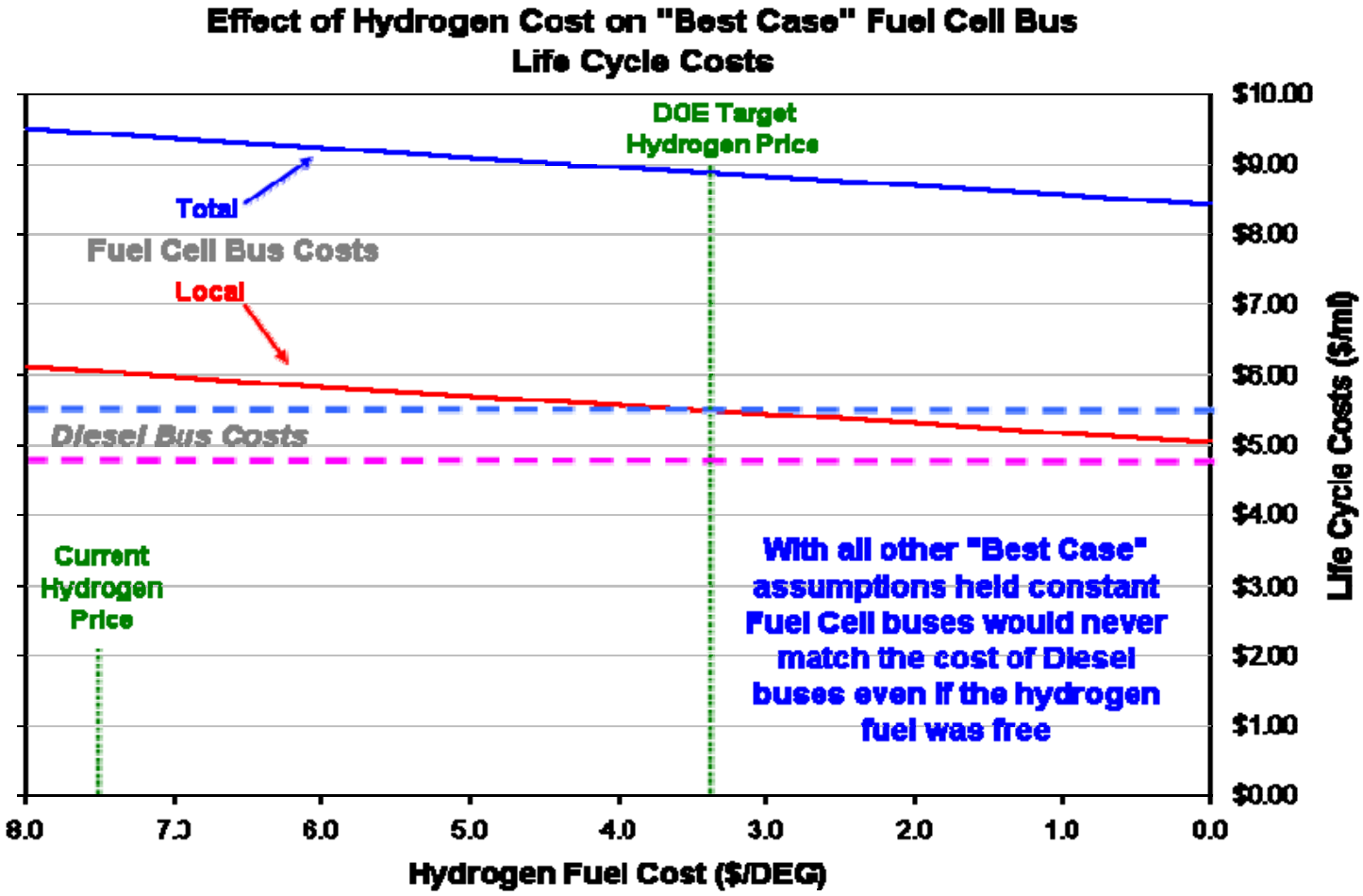
Effect of Hydrogen Price



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Best Case Summary

- Under the "Best Case" near-term scenario, if all FTA and DOE cost targets are met, total life cycle costs for Fuel Cell Hybrid buses fall by 40% compared to the base case, but
  - Total per-mile costs will still be $3.30/mi more than total costs for Diesel buses
  - Local per-mile costs will still be $0.58/mi more than local costs for Diesel buses
- Under the Best Case scenario the greatest contributor to increased life cycle costs for Fuel Cell Hybrid buses is still the bus purchase price

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Best Case Summary (cont.)

- With all other best case assumptions held constant the purchase price of a Fuel Cell Hybrid bus would have to fall significantly for life cycle costs to match those of a diesel bus:
  - $500,000/bus to match diesel local life cycle costs (~ equivalent to current Hybrid Diesel bus price)
  - $350,000/bus to match diesel total life cycle costs (less than the price of a current CNG bus)
- Even if hydrogen fuel was free, life time fuel cost savings from a Fuel Cell Hybrid bus would not exceed the Best Case assumed bus purchase price premium compared to Diesel buses