Hydrogen Workshop for Fleet Operators

ALLIANCE TECHNICAL SERVICES, Inc.

Module 8, “Hydrogen Lifecycle Costs, Training & Useful Information”

ALLIANCE TECHNICAL SERVICES, Inc.

Hydrogen Lifecycle Cost, Training & Useful Information Outline

1. Lifecycle Costs
   - Fuel Cell System and Fuel Cell Bus Cost
   - Fuel Cell System and Hybrid Fuel Cell Bus Cost
   - Forecast Prices for 40’ Transit Buses
   - Annual Maintenance Costs
   - Cost of Hydrogen
   - Cost of Fuel Per Mile
   - Lifecycle Cost for a 250 Transit Bus Fleet
2. Hydrogen Fuel Training
3. Useful Hydrogen Links

The Santa Clara Valley Transportation Authority total program budget is $18,450,000. This includes $10,565,000 for three buses and $3,103,000 for facilities

Fuel Cell System and Bus Costs

Sources:

1. Reliable industry sources indicate that the actual direct cost of a fuel cell stack (material, labor, and overhead) is $3,600/kW ($2,690/hp), which represents 70% of the total price of $6,840/kW ($5,100/hp)
2. Published prices ranging between $6,000/kW ($4,480/hp) and $9,000/kW ($6,700/hp) for an average of $7,500/kW ($5,600/hp)
3. DOE technical target for 2015 of $30/kW ($22/hp), including storage. An average of $37.5/kW ($28/hp) was used, storage not included, as a conservative figure
4. Evobus CUTE price in 2003 of $1.38 million ($1.2 million Euros)
5. Recent North American transaction of $1.4 million for Chicago Transit and $924,000 for BC Transit for an average of $1,162,000

"Transforming the Future: Moving Toward the Fuel Cell-Powered Fleets in Canadian Urban Transit Systems", Natural Resources Canada, February 2005

Fuel Cell System and Bus Costs

Cost of 200 kW (270 hp) Fuel Cell ($)			Fuel Cell Bus Cost ($)	
	2004	2015	2004	2015
Sources				
1	1,368,000	109,000	1,505,000	768,000
2	1,500,000	159,000	1,976,000	818,000
3		7,500		666,500
4	904,000	96,000	1,380,000	755,000
5	924,000	98,000	1,400,000	757,000
Average			**1,565,250**	**752,900**

"Transforming the Future: Moving Toward the Fuel Cell-Powered Fleets in Canadian Urban Transit Systems", Natural Resources Canada, February 2005

Fuel Cell Hybrid Bus Costs

Cost of 120 kW (160 hp) Fuel Cell ($)			Fuel Cell Hybrid Bus Cost ($)	
	2004	2015	2004	2015
Sources				
1	617,000	65,500	1,122,750	765,000
2	900,000	95,500	1,405,500	795,000
3		4,500		704,330
4	542,400	57,500	1,048,000	757,250
5	554,400	58,750	1,060,000	758,500

"Transforming the Future: Moving Toward the Fuel Cell-Powered Fleets in Canadian Urban Transit Systems", Natural Resources Canada, February 2005

Forecast Prices for 40' Transit Buses

Bus Type	2004 Price ($)	2015 Price ($)	Rational and Calculations
Diesel	300,000	450,000	Impact of inflation
Diesel Hybrid	500,000	700,000	Reliable bus industry sources and sales to Seattle, SEPTA, NYCTA and BC Transit. NYCTA paid $385,000 for its diesel hybrid buses. This special price will not be offered to other transit systems. Commercial bids are expected to be approximately $500,000
Fuel Cell Hybrid	1,159,000	756,000	Sources 1, 2, 3, 4 & 5
Fuel Cell	1,565,250	752,900	Sources 1, 2, 3, 4 & 5

Source: MARCON-DDM HIT, 2004

"Transforming the Future: Moving Toward the Fuel Cell-Powered Fleets in Canadian Urban Transit Systems", Natural Resources Canada, February 2005

Annual Maintenance Costs

Maintenance Cost Per Bus	2004 ($)	2015 ($)
Diesel	28,500	39,500
Diesel Hybrid	Not Available	No Forecast
Fuel Cell	24,000	33,500
Fuel Cell Hybrid	22,500	31,000

Baseline maintenance costs for current fleets were based on the results of interviews and with representatives from 16 transit fleets participating in the study. Using the current baseline for a 40' transit bus, it is estimated that a fuel cell bus will be 15% less to maintain than a diesel bus and a fuel cell hybrid bus would be approximately 21% less to maintain than a diesel bus. Inflation was also taken into account in the forecast model.

"Transforming the Future: Moving Toward the Fuel Cell-Powered Fleets in Canadian Urban Transit Systems", Natural Resources Canada, February 2005

Cost of Hydrogen in 2015

Cost per kg of Hydrogen ($)	DOE Scenario	Conservative Scenario
On-site reforming of natural gas	1.58	2.60
On-site water electrolysis	2.63	4.23
Off-site merchant liquid hydrogen	2.89	4.60

Source: MARCON-DDM HIT, 2004

The alternate forecast is based on DOE targets adjusted to take into consideration for more current energy prices forecasts (natural gas at $\$0.55/m^3$ and electricity at $0.105/kWh as well as new technological developments

"Transforming the Future: Moving Toward the Fuel Cell-Powered Fleets in Canadian Urban Transit Systems", Natural Resources Canada, February 2005

Cost of Fuel Per Mile in 2015

	Diesel Price* per Gallon: $2.20	Diesel Price* per Gallon: $3.00
Diesel (4.2 mpg)	0.52/mile	0.71/mile
Diesel Hybrid	Not Available	No Forecast
	Hydrogen Price per kg: $2.60**	**Hydrogen Price** per kg: $4.60**
Fuel Cell (6.2 mpg)	0.42/mile	0.74/mile
Fuel Cell Hybrid (9.4 mpg)	0.28/mile	0.48/mile

Source: MARCON-DDM HIT, 2004

* All taxes included

** Assuming there will be no taxes on hydrogen

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Lifecycle Costs for 250 Buses over 18 Years

250 Bus Fleet Acquisition Cost		
	Diesel	112,500,000
	Fuel Cell	188,225,000
	Fuel Cell Hybrid	189,000,000
Operations Cost		
Maintenance Cost		
	Diesel	178,000,000
	Fuel Cell	150,000,000
	Fuel Cell Hybrid	140,000,000
Fuel Cost		
(Diesel @ $3.00/gallon)	Diesel	117,000,000
(Hydrogen @ $2.60/kg)	Fuel Cell	70,000,000
(Hydrogen @ $2.60/kg)	Fuel Cell Hybrid	45,500,000

Total Cost	
Diesel	407,500,000
Fuel Cell	408,225,000
Fuel Cell Hybrid	374,500,000

Source: MARCON-DDM HIT, 2004

"Transforming the Future: Moving Toward the Fuel Cell-Powered Fleets in Canadian Urban Transit Systems", Natural Resources Canada, February 2005

Hydrogen Fuel Training

- Air Products' KnowH2ow Safety Service
  - Hydrogen safety training
  - Equipment and operational review
  - On-site system audits
  - Safety consultation
  - Safe operating procedures
  - Operational readiness inspections
  - Emergency response training
  - Courses can be customized to meet specific needs

Air Products and Chemicals, Inc

Hydrogen Fuel Training

Air Products' KnowH2ow Safety Training Program

- Hydrogen properties
- Modern approach to safety
- Hydrogen safety concerns
- Releases of hydrogen into the air
- Hydrogen operating practices
- Hydrogen production and applications
- Leak detection equipment
- Indoor hydrogen safety considerations
- Liquid hydrogen considerations
- Vehicle and hydrogen fueling considerations
- Differentiation from natural gas
- Emergency response
- Codes, standards, and guidelines
- Hydrogen design considerations

Air Products and Chemicals, Inc

Hydrogen Fuel Training

Hydrogen Safety, LLC SAFEH2 Industrial Training

- Overview of the types of hydrogen hazards
- Respect for the power of hydrogen
- Hydrogen safety-related properties
- Combustion hazards
- Pressure and low temperature hazards
- How hydrogen hazards are addressed
- Proven principles and practices
- Control of hazards
- Component design concerns
- Safety management concerns
- Storage, piping, disposal, and ventilation
- Detailed facility design and safety concerns
- Elements of hazards analysis
- Risk management strategies

Hydrogen Safety, LLC

Hydrogen Fuel Training

- DOE Alternative Fuel Driver Training
  - Sponsored by EPAct and Clean Cities
  - Safely operate alternative fuel vehicles
  - Properly fuel alternative fuel vehicles
  - What to do in case of an emergency
- AFV Training Network
  - International/domestic AFV program management
  - Codes and standards development
  - Grant writing
  - Transition to alternative fuels
  - AFV marketing and sales support

Useful Hydrogen Links

- Gasoline and diesel fuel updates

http://tonto.eia.doe.gov/oog/info/gdu/gasdiesel.asp

- DOE Hydrogen Program

http://www.hydrogen.energy.gov/

- California Hydrogen Highway

http://www.hydrogenhighway.ca.gov/

- International hydrogen efforts
  - Europe

http://europa.eu.int/comm/energy_transport/en/cut_en.html

- International Hydrogen Efforts
  - Ecological City Transport System (ECTOS)

http://www.hydro.com/en/our_business/oil_energy/new_energy/hydrogen/ectos.html

  - International Energy Agency Hydrogen Program

http://www.ieahia.org/

- Hydrogen Basics
  - National Hydrogen Association

http://www.hydrogenus.com/

Useful Hydrogen Links

- Hydrogen Basics
  - Hydrogen, Fuel Cells & Infrastructure Technologies Program

http://www.eere.energy.gov/hydrogenandfuelcells/

- Hydrogen Combustion Properties
  - College of the Desert

http://www.eere.energy.gov/hydrogenandfuelcells/tech_validation/h2_manual.html

- Hydrogen Production, Delivery and Storage
  - Air Products

http://www.airproducts.com/

- Hydrogen Production, Delivery and Storage
  - Praxair

http://www.praxair.com/

  - Quantum Technologies

http://www.qtww.com/index.php

  - Linde

http://www.linde-gas.com

  - National Renewable Energy Laboratory

http://www.nrel.gov/hydrogen/

- Hydrogen Fueling Stations
  - California Fuel Cell Partnership

http://www.fuelcellpartnership.org/

Useful Hydrogen Links

- Hydrogen Facility Requirements
  - National Fire Protection Association

http://www.nfpa.org

- Hydrogen Facility Requirements
  - Federal Transit Administration

http://www.fta.dot.gov/

- Hydrogen Internal Combustion Engines
  - Hydrogen Engine Center

http://www.hydrogenenginecenter.com/

  - Ford Motor Company

http://www.ford.com/en/innovation/engineFuelTechnology/hydrogenInternalCombustion.htm

- How a Fuel Cell Works
  - How Stuff Works

http://www.howstuffworks.com/

  - Ballard Power Systems

http://www.ballard.com/

  - Fuel Cells 2000

http://www.fuelcells.org/

- Light-Duty Hydrogen Vehicles
  - Energy Efficiency and Renewable Energy

http://www.fueleconomy.gov/feg/fuelcell.shtml

Useful Hydrogen Links

- Light-Duty Hydrogen Vehicles
  - Fuel Cells 2000

http://www.fuelcells.org/info/charts.html

- Transit Hydrogen Vehicles
  - ISE Corporation

http://www.isecorp.com/

  - Ford Motor Company

http://media.ford.com/newsroom/feature_display.cfm?release=18979

  - Fuel Cells 2000

http://www.fuelcells.org/info/charts.html

- Specialty Hydrogen Vehicles
  - Fuel Cells 2000

http://www.fuelcells.org/info/charts.html

- Hydrogen Training
  - Air Products

http://www.airproducts.com/

  - Hydrogen Safety, LLC

http://www.hydrogensafety.com/

  - Alternative Fuel Driver Training

http://www.eere.energy.gov/afdc/resources/altfueltraining/driver_training.html

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