Appendix B – GPRA07 Hydrogen, Fuel Cells, and Infrastructure Technologies (HFCIT) Program Documentation

1. Introduction

The target markets for the Office of Hydrogen, Fuel Cells, and Infrastructure Technologies (HFCIT) program include transportation (cars and light trucks) and stationary (particularly residential and commercial) applications. The two main markets will be discussed separately below.

1.1 Target Market: Fuel Cell Vehicle Market

The market for fuel cell vehicles (FCVs) includes all cars and light trucks sold for both personal and business use. Today, the size of this market is approximately 17 million vehicle sales per year. Total car and light-truck stock is about 220 million vehicles. EIA projects both sales and stock to grow to more than 20 million and 300 million respectively by 2025. Additional growth is expected post-2025, as explained in Chapter 3. The vehicle miles of travel are projected to grow from 3.28 trillion in 2020 to 5.63 trillion in 2050.

1.2 Key Factors in Shaping the Market Adoption of FCVs

Key factors associated with the adoption of new vehicle technologies include how the new vehicle technologies compare with the baseline vehicle technologies in terms of the following vehicle attributes:

- Vehicle Price
- Fuel Economy
- Range
- Maintenance Cost
- Acceleration
- Top Speed
- Luggage Space

Of these, vehicle price and fuel economy are the most important.

Nonvehicle attributes that are important factors in a consumer's decision to purchase new vehicle technologies include the following:

- Fuel Price
- Fuel Availability

1.3 Methodology and Calculations

The factors listed above include the factors used in the modeling of new vehicle technology penetration by the NEMS and MARKAL models. FCV attributes and other factors are discussed below.

1.3.1 FCV Attributes

FCV attributes were developed based on the HFCIT program goals, discussions with HFCIT program managers, Powertrain Systems Analysis Toolkit (PSAT) modeling, and payback analysis (Refs. 1-5). The PSAT model is a simulation model used by DOE to evaluate the fuel economy and performance of light vehicles using various technologies. (See Section 1.3.2 of Appendix F for a discussion of how the fuel economies of FCVs and other advanced technology vehicles are estimated in GPRA 07).

Payback analysis was used to estimate what the incremental price of FCVs would be when they become cost competitive with conventional vehicles, a goal of the program. (The incremental price equals the present value of the energy cost reduction achieved by FCVs over three years, assuming a hydrogen price of $1.50/gallon gasoline equivalent and 7.5% discount rate. See Section 1.3.3 of Appendix F for additional discussion of how the incremental prices of FCVs and other advanced technology vehicles are estimated in GPRA 07.) Other attributes were based on a review of past GPRA characterizations (e.g., Ref. 6).

Because the NEMS and MARKAL models require different levels of detail, two separate vehicle characterizations are provided. In both cases, most of the attributes are provided as ratios to the vehicle attributes of conventional vehicles. (For NEMS, the $ value of the price increments were provided.) The attributes are for new vehicles in the year listed. The conventional vehicles to which the FCVs are compared are the conventional vehicles of the AEO 2004 Reference Case extended to 2050 with modest increases in fuel economy. (See Appendix A for the description of the GPRA 07 Baseline.)

Table 1 contains the vehicle attributes for FCVs provided for input to the NEMS model. Attributes are provided for six car size classes and six light-truck classes. **Table 2** contains vehicle attributes for FCVs provided as input to the MARKAL model. MARKAL uses only vehicle price and fuel economy attributes. MARKAL does not disaggregate cars and light trucks into various classes.

1.3.2 Hydrogen Price

HFCIT Program goals were used to estimate capital and O&M costs and production efficiencies for distributed natural gas reformers, central biomass gasifiers, distributed ethanol reformers, and central and distributed electrolytic production technologies. Assumptions for central coal and natural gas production technologies were adapted from H2A analysis results. The infrastructure requirements and operating costs for the widespread distribution of hydrogen vary widely by distance and method. As a simplifying assumption, a flat cost of $5.28 per MMBtu—or $0.65 per gallon of gasoline equivalent (gge)[1]—was assumed for hydrogen distribution costs based on published data from NREL.[2] We will be enhancing the representation of the distribution and fueling costs for hydrogen in future analysis as data becomes available. **Table 3** shows projected

[1] One kilogram of hydrogen is roughly equivalent in energy content to 1 gallon of gasoline, and is often referred to as a gallon of gasoline equivalent (gge).

[2] Amos W.A., Lane J.M., Mann M.K., and Spath P.L. *Update of hydrogen from biomass – determination of the delivered cost of hydrogen*, NREL, 2000.

hydrogen costs by cost component for the Hydrogen Program Case. Due to market factors affecting feedstock costs, the projected costs do not always match HFCIT Program goals.

1.3.3 Hydrogen Availability at Stations

An availability factor for hydrogen refueling stations is required by the NEMS model. The assumptions used are as follows: 1) hydrogen (H2) will not be available at any stations until sometime between 2015 and 2020; 2) in 2020, H2 will be available at 10% of all U.S. service stations and 3) H2 will be available at 25% of all U.S. service stations by 2025. These assumptions were provided by the HFCIT program.

1.3.4 FCV Market Penetration Methodology

Brief descriptions of how the NEMS and MARKAL models project new vehicle technology penetration using these vehicle attributes can be found in **Chapter 2** (NEMS) and **Chapter 3** (MARKAL).

1.4 Sources

1. "Hydrogen, Fuel Cells & Infrastructure Technologies Program: Multi-Year Research, Development and Demonstration Plan" (Draft), U.S. Department of Energy, Energy Efficiency and Renewable Energy (June 3, 2003).

2. PSAT (POWERTRAIN SYSTEM ANALYSIS TOOLKIT): see http://www.transportation.anl.gov/software/PSAT/

3. Phillip Sharer and Aymeric Rousseau, "PSAT Results for GREET and GPRA – FE Adjusted 081705.xls," August 17, 2005.

4. Rousseau, Aymeric, "Number Associated with Presentation," July 6, 2005.

5. Payback model developed by Jim Moore, TA Engineering (2003) and expanded by Margaret Singh, ANL (2005).

6. "Program Analysis Methodology: Office of Transportation Technologies, Quality Metrics 2003 Final Report," prepared by OTT Analytic Team, for Office of Transportation Technologies, U.S. Department of Energy (March 2002).

Table 1. FCV Attributes Input to NEMS
(All units are ratios to the conventional gasoline vehicles of the specific year, except for the incremental price which is in 2003$)

	2-SEATER		MINI-COMPACT		SUB-COMPACT		COMPACT	
Fuel Cell (H2)	**2022**	**2025**	**2022**	**2025**	**2022**	**2025**	**2022**	**2025**
Incremental Vehicle Price ($)	2392	1611	2311	1559	1964	1325	1991	1345
Range	0.90	0.96	0.90	0.96	0.90	0.96	0.90	0.96
Maintenance Cost	1.05	1.02	1.05	1.02	1.05	1.02	1.05	1.02
Acceleration	1.00	1.06	1.00	1.06	1.00	1.06	1.00	1.06
Top Speed	0.90	0.93	0.90	0.93	0.90	0.93	0.90	0.93
Luggage Space	0.80	0.86	0.80	0.86	0.80	0.86	0.80	0.86
Fuel Economy (a)	2.37	2.43	2.37	2.43	2.37	2.43	2.37	2.43

	MEDIUM CAR			LARGE CAR		
Fuel Cell (H2)	**2018**	**2023**	**2025**	**2018**	**2023**	**2025**
Incremental Vehicle Price ($)	2251	1661	1613	2415	1775	1722
Range	1.00	1.00	1.00	1.00	1.00	1.00
Maintenance Cost	1.05	1.00	0.97	1.05	1.00	0.97
Acceleration	1.00	1.00	1.04	1.00	1.00	1.04
Top Speed	0.85	0.9	0.92	0.85	0.9	0.92
Luggage Space	0.90	1.00	1.00	0.90	1.00	1.00
Fuel Economy (a)	2.28	2.38	2.42	2.28	2.38	2.42

(a) Gasoline gallon equivalent

Table 1 (continued).

Fuel Cell (H2)	SMALL SUV 2020	SMALL SUV 2025	LARGE SUV 2018	LARGE SUV 2023	LARGE SUV 2025	SMALL TRUCK 2020	SMALL TRUCK 2025	CARGO (Incl. 2b) TRUCK 2024	CARGO (Incl. 2b) TRUCK 2025
Incremental Vehicle Price ($)	2626	1879	3281	2350	2242	2342	1685	2802	1861
Range	0.90	1.00	1.00	1.00	1.00	0.90	1.00	0.90	0.93
Maintenance Cost	1.10	1.00	1.05	1.00	0.97	1.10	1.00	1.05	1.04
Acceleration	1.00	1.10	1.10	1.10	1.10	1.00	1.10	1.00	1.00
Top Speed	0.90	0.95	0.90	0.95	0.95	0.90	0.95	0.90	0.90
Luggage Space	0.90	0.95	0.95	1.00	1.00	0.90	0.95	0.90	0.91
Fuel Economy (a)	2.37	2.35	2.36	2.36	2.35	2.16	2.16	2.16	2.16

Fuel Cell (H2)	MINIVAN 2020	MINIVAN 2025	LARGE VAN 2018	LARGE VAN 2023	LARGE VAN 2025
Incremental Vehicle Price ($)	2535	1821	3178	2267	2158
Range	0.90	1.00	1.00	1.00	1.00
Maintenance Cost	1.10	1.00	1.05	1.00	0.97
Acceleration	1.00	1.10	1.10	1.10	1.10
Top Speed	0.90	0.95	0.90	0.95	0.95
Luggage Space	0.90	0.95	0.95	1.00	1.00
Fuel Economy (a)	2.37	2.35	2.36	2.36	2.35

(a) Gasoline gallon equivalent

Table 2. FCV Attributes for Input to MARKAL

		Ratios to Conventional Vehicles					
		2010	2020	2025	2030	2035	2050
CARS	MPG	2.12	2.32	2.42	2.54	2.67	2.95
	Incremental Price			1.061			1.036
LIGHT TRUCKS	MPG	2.21	2.30	2.29	2.27	2.26	2.73
	Incremental Price			1.063			1.036

Table 3. Hydrogen Production Costs by Technology and Component (2003 $/gge)

Central Coal - No Co-product						
Unit Costs	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Capital Costs	0.65	0.65	0.65	0.65	0.65	0.65
O&M	0.23	0.23	0.23	0.23	0.23	0.23
Feedstock Costs	0.20	0.24	0.26	0.27	0.29	0.32
Plant Gate	**1.08**	**1.12**	**1.14**	**1.14**	**1.17**	**1.20**
Distribution, Storage & Tax	1.23	1.23	1.23	1.23	1.23	1.23
Total	**2.30**	**2.34**	**2.36**	**2.37**	**2.39**	**2.42**

Central Coal - with Elec Co-product						
Unit Costs	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Capital Costs		1.11	1.11	1.11	1.11	1.11
O&M		-0.24	-0.23	-0.19	-0.20	-0.21
Feedstock Costs		0.31	0.34	0.34	0.38	0.41
Plant Gate		1.18	1.21	1.26	1.28	1.31
Distribution, Storage & Tax		1.23	1.23	1.23	1.23	1.23
Total		2.40	2.44	2.48	2.51	2.54

Remote Gas Reformer						
Unit Costs	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Capital Costs	0.58	0.58	0.58	0.58	0.58	0.58
O&M	0.46	0.46	0.46	0.46	0.46	0.46
Feedstock Costs	0.94	0.91	0.94	0.97	1.02	1.13
Plant Gate	1.98	1.95	1.98	2.01	2.07	2.18
Distribution, Storage & Tax	0.46	0.46	0.46	0.46	0.46	0.46
Total	2.44	2.41	2.44	2.47	2.53	2.64

Central Gas Reformer						
Unit Costs	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Capital Costs	0.21	0.21	0.21	0.21	0.21	0.21
O&M	0.10	0.10	0.10	0.10	0.10	0.10
Feedstock Costs	1.02	0.98	1.02	1.06	1.13	1.25
Plant Gate	1.33	1.29	1.33	1.37	1.44	1.56
Distribution, Storage & Tax	1.23	1.23	1.23	1.23	1.23	1.23
Total	2.56	2.52	2.56	2.59	2.66	2.79

Central Biomass						
Unit Costs	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Capital Costs	0.42	0.42	0.42	0.41	0.41	0.41
O&M	0.26	0.26	0.26	0.26	0.26	0.26
Feedstock Costs	0.35	0.35	0.35	0.35	0.40	0.52
Plant Gate	1.04	1.04	1.04	1.03	1.08	1.20
Tax	1.23	1.23	1.23	1.23	1.23	1.23
Total	2.26	2.26	2.26	2.25	2.31	2.42

Distributed Ethanol						
Unit Costs	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Capital Costs	0.44	0.44	0.44	0.44	0.44	0.44
O&M	0.50	0.50	0.50	0.50	0.50	0.50
Feedstock Costs	2.44	2.45	2.43	2.33	2.35	2.35
Plant Gate	3.39	3.39	3.38	3.28	3.29	3.30
Distribution, Storage & Tax	0.46	0.46	0.46	0.46	0.46	0.46
Total	3.85	3.85	3.84	3.74	3.75	3.76

Central Electrolytic H2 - Grid or Wind

Unit Costs	2025	2030	2035	2040	2045	2050
Capital Costs	0.23	0.23	0.23	0.23	0.23	0.23
O&M	0.10	0.10	0.10	0.10	0.10	0.10
Feedstock Costs	2.94	2.18	2.16	2.02	2.05	2.22
Plant Gate	3.28	2.52	2.50	2.36	2.39	2.56
Distribution & Storage*	1.23	1.23	1.23	1.23	1.23	1.23
Total	4.51	3.75	3.72	3.58	3.62	3.78

Distributed Electrolytic H2

Unit Costs	2025	2030	2035	2040	2045	2050
Capital Costs	0.66	0.66	0.66	0.66	0.66	0.66
O&M	0.50	0.50	0.50	0.50	0.50	0.50
Feedstock Costs	3.16	2.35	2.32	2.17	2.21	2.39
Plant Gate	4.33	3.51	3.49	3.34	3.37	3.55
Distribution, Storage & Tax	0.46	0.46	0.46	0.46	0.46	0.46
Total	4.79	3.97	3.95	3.80	3.83	4.01

2.1 Stationary Fuel Cell Market
Stationary fuel cells are one of a variety of distributed electricity-generation technologies. The particular market sectors in which stationary fuel cells are most applicable include residential and commercial applications.

2.2 Key Factors in Shaping the Market Adoption of Stationary Fuel Cells
Key factors associated with the market penetration of stationary fuel cells include the energy efficiency (electrical and combined heat and power), installed cost, and maintenance cost of the fuel cells relative to other distributed and traditional electricity-generation technologies.

2.3 Methodology and Calculations

2.3.1 Baseline Assumptions for Stationary Fuel Cells
There were no changes in the technology assumptions for distributed generation, including stationary fuel cells, from AEO 2004 to AEO2005. There remain a few definitional differences in how the HFCIT Program goals are stated and how the technology characterizations are used within NEMS. There also remains a difference in the view of current (or nearly current) technology that might reflect different trade-offs of efficiency and costs or may reflect differences in development. In either case, the same 2005 values should be used for the GPRA Baseline and Program cases so the Baseline was modified to reflect the Program view of 2005. As described below, the Program values were first adjusted to the same definitions as used in NEMS. By 2010, the Baseline returns to the AEO2005 values, with higher efficiencies and also higher costs than the values for 2005. Because of their relatively high costs, fuel cells are not cost-effective in the early years regardless of which source of data is used.

Residential 5kW PEMFC Baseline

AEO2005 Reference Case

Year	CHP System Efficiency	Electrical Efficiency	Installed Cost (2003 $/kW)	Maint. Cost (2003$/kW-yr)
2005	0.690	0.300	5500	264
2010	0.700	0.320	3800	184
2015	0.710	0.335	3000	168
2020	0.720	0.350	2200	152
2025	0.725	0.355	1750	140

GPRA07 Baseline

Year	CHP System Efficiency	Electrical Efficiency	Installed Cost (2003 $/kW)	Maint. Cost (2003$/kW-yr)
2005	0.675	0.288	2300	264
2010	0.700	0.320	3800	184
2015	0.710	0.335	3000	168
2020	0.720	0.350	2200	152
2025 to 2050	0.725	0.355	1750	140

Commercial 200kW Fuel Cell Baseline

AEO2005 Reference Case

Year	CHP System Efficiency	Electrical Efficiency	Installed Cost (2003 $/kW)	Maint. Cost (2003$/kW-yr)
2005	0.750	0.360	5200	232
2010	0.720	0.490	2500	128
2015	0.720	0.500	2150	124
2020	0.720	0.510	1800	120
2025	0.735	0.520	1450	112

GPRA07 Baseline

2005	0.675	0.288	1930	232
2010	0.720	0.490	2500	128
2015	0.720	0.500	2150	124
2020	0.720	0.510	1800	120
2025 to 2050	0.735	0.520	1450	112

2.3.2 Program Case Assumptions for Stationary Fuel Cells

Assumptions for distributed PEM fuel cells are based on the multiyear program plan (Ref.1). Capital costs and efficiencies were provided in the MYPP for the years 2005 and 2010. The costs are assumed to be in year 2003 dollars. No values were listed for maintenance costs, so the AEO2005 values are used The costs and efficiencies assumed for NEMS by 2025 were held constant through 2050 in MARKAL.

The program goal capital costs were increased to account for the installation cost that is assumed in the Baseline fuel cells costs from the NREL report. In addition, the efficiencies in the multiyear plan are expressed in lower heating values and were converted to higher heating value efficiencies for use in NEMS.

Residential 5kW PEMFC Program Case

HFCIT Goals from Multiyear Plan

Year	CHP System Efficiency*	Electrical Efficiency*	Equip. Cost (2003 $/kW)	Maint. Cost (2003$/kW-yr)
2005	0.75	0.32	1500	n/a
2010	0.80	0.35	1000	n/a

* based on LHV on input fuel

Model Inputs for HFCIT Goals

Year	CHP System Efficiency	Electrical Efficiency	Installed Cost (2003 $/kW)	Maint. Cost (2003$/kW-yr)
2005	0.675	0.288	2300	264
2010	0.720	0.315	1800	184
2015	0.720	0.315	1800	168
2020	0.720	0.315	1800	168
2025 to 2050	0.720	0.315	1800	168

Commercial 200kW Fuel Cell Program Case

HFCIT Goals from Multiyear Plan

Year	CHP System Efficiency*	Electrical Efficiency*	Equip. Cost (2003 $/kW)	Maint. Cost (2003$/kW-yr)
2005	0.75	0.32	1250	n/a
2010	0.80	0.40	750	n/a

* based on LHV on input fuel

Model Inputs for HFCIT Goals

Year	CHP System Efficiency	Electrical Efficiency	Installed Cost (2003 $/kW)	Maint. Cost (2003$/kW-yr)
2005	0.675	0.288	1930	232
2010	0.720	0.360	1430	128
2015	0.720	0.360	1430	128
2020	0.720	0.360	1430	128
2025 to 2050	0.720	0.360	1430	128

2.4 Sources

1. "Hydrogen, Fuel Cells & Infrastructure Technologies Program: Multi-Year Research, Development and Demonstration Plan" (Draft), U.S. Department of Energy, Energy Efficiency and Renewable Energy (June 3, 2003).