Appendix G – GPRA05 Hydrogen, Fuel Cells, and Infrastructure Technologies Program Documentation

Fuel Cell Vehicles

Fuel cell vehicle (FCV) attributes were based on the Hydrogen, Fuel Cells, and Infrastructure Technologies (HFCIT) program goals, discussions with HFCIT program managers, and technical analysis by contractors (Ref. 1). Because the two models (NEMS-GPRA05 and MARKAL-GPRA05) that generate GPRA results require different levels of detail, the technical characterizations were provided in two parts: one for input to NEMS-GPRA05 and one for input to MARKAL-GPRA05. The discussion of the light-vehicle (LV) characterization is divided into two parts below.

Input to NEMS-GPRA05

Table 1 contains vehicle attributes for FCVs operating on hydrogen (H2) delivered to the FCV as H2 (Fuel Cell Hydrogen), and FCVs operating on H2 reformed from onboard gasoline (Fuel Cell Gasoline). These advanced technologies may be used in cars and light trucks (LTs). Attributes are provided for the two technologies in up to two car size classes and three LT classes. The attributes are for new vehicles in the year listed. The attributes include the following:

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

The attributes for the two technologies are provided as ratios to the vehicle attributes of conventional vehicles.

The attributes of the two advanced technologies vary over time. The two technologies are at different stages of technology development and, thus, are expected to penetrate the LV market at different times. In fact, FCVs operating on gasoline are expected to enter the new vehicle market first, but be out of it by 2030. The attributes were implemented in NEMS-GPRA05 as step-functions over time.

Using the program's vehicle-attribute characterization provided in **Table 1**, attributes were assigned to the six car size classes and six LT classes used in NEMS-GPRA05. The results are shown in **Table 2**.

Input to MARKAL-GPRA05

The MARKAL-GPRA05 model provides benefits estimates for the GPRA analysis out to 2050. The model does not require LV characterization at the level of detail that NEMS-GPRA05 does. There is no disaggregation of cars and LTs into size classes, and only cost and fuel economy ratios are required. **Table 3** presents the LV characterization input to MARKAL-GPRA05.

Table 1. Attributes of Fuel Cell Vehicles Relative to Conventional Vehicles

	SMALL CARS			LARGE CARS		
Fuel Cell Hydrogen	**2018**	**2020**	**2025**	**2016**	**2020**	**2025**
Vehicle Price	1.050	1.030-1.040	1.020-1.037	1.100	1.050	1.025-1.029
Range	1.00	1.00	1.00	1.00	1.00	1.00
Maintenance Cost	1.05	1.00	0.93	1.05	1.00	0.93
Acceleration	1.10	1.10	1.10	1.00	1.00	1.10
Top Speed	0.95	0.95	0.95	0.75	0.90	0.95
Luggage Space	1.00	1.00	1.00	1.00	1.00	1.00
Fuel Economy*	2.50	2.70	3.00	2.20	2.50	3.00

Fuel Cell Gasoline				**2010**	**2020**	**2025**
Vehicle Price				1.300	1.200	1.150
Range				1.00	1.00	1.00
Maintenance Cost				1.05	1.00	0.93
Acceleration				1.00	1.00	1.00
Top Speed				1.00	1.00	1.00
Luggage Space				0.90	1.00	1.00
Fuel Economy*				1.50	1.80	2.00

	MINI-VAN			SUV				CARGO TRUCK		
Fuel Cell Hydrogen	**2014**	**2020**	**2025**	**2012**	**2015**	**2020**	**2025**	**2012**	**2020**	**2025**
Vehicle Price	1.200	1.035	1.031	1.250	1.100	1.030-1.035	1.030-1.033	1.250	1.04-1.050	1.038-1.045
Range	0.90	1.00	1.00	0.90	1.00	1.00	1.00	0.90	1.00	1.00
Maintenance Cost	1.10	1.00	0.95	1.05	1.05	1.00	1.00	1.05	1.00	0.93
Acceleration	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.00	1.00	1.00
Top Speed	0.90	0.95	0.95	0.90	0.90	0.95	0.95	0.90	0.90	0.95
Luggage Space	0.90	1.00	1.00	0.90	1.00	1.00	1.00	0.80	1.00	1.00
Fuel Economy*	2.00	2.50	3.00	2.00	2.30	2.50	2.50	2.00	2.50	3.00

Fuel Cell Gasoline	**2010**	**2020**	**2010**	**2020**
Vehicle Price	1.300	1.200	1.300	1.200
Range	1.00	1.00	1.00	1.00
Maintenance Cost	1.05	1.00	1.05	1.00
Acceleration	1.00	1.00	1.00	1.00
Top Speed	1.00	1.00	1.00	1.00
Luggage Space	0.90	1.00	0.90	1.00
Fuel Economy*	1.40	1.80	1.40	1.80

*** Gasoline equivalent**

Table 2. Vehicle Cost Ratios by Car and LT Class Size

Fuel Cell Hydrogen

Small cars	2018	2020	2025
2-seater	1.05	1.03	1.025
Mini-compact	1.05	1.03	1.020
Subcompact	1.05	1.04	1.037
Compact	1.05	1.04	1.037

Large Cars	2016	2020	2025
Midsize	1.1	1.05	1.029
Large	1.1	1.05	1.025

Mini Van	2014	2020	2025
Min-van	1.2	1.035	1.031

Fuel Cell Gasoline[1]

Large Cars	2010	2020	2025
Midsize	1.3	1.2	1.015
Large	1.3	1.2	1.015

Mini Van	2010	2020
Min-van	1.3	1.2

Fuel Cell Hydrogen

SUVs	2012	2015	2020	2025
Small	1.25	1.1	1.035	1.033
Large	1.25	1.1	1.03	1.03

Cargo Truck	2012	2020	2025
Large Van	1.25	1.035	1.032
Small Pickup	1.25	1.03	1.045
Large Pick up	1.25	1.04	1.038

Fuel Cell Gasoline

SUVs	2010	2020
Small	1.3	1.2
Large	1.3	1.2

[1] No small fuel cell gasoline cars were characterized.

Table 3. Light-Vehicle Characteristics for Analysis of HFCIT Program Using MARKAL-GPRA05 Model

Vehicle Type	Technology	Ratio	2010	2015	2020	2025	2030	2040	2050
Car	Fuel Cell Gasoline	Cost	1.30		1.20	1.15			
		MPG*	1.50		1.80	2.00			
	Fuel Cell Hydrogen	Cost		1.10	1.05	1.05	1.05	1.05	1.05
		MPG*		2.20	2.50	3.00	3.20	3.40	3.40
LT	Fuel Cell Gasoline	Cost	1.30		1.20				
		MPG*	1.40		1.80				
	Fuel Cell Hydrogen	Cost	1.25	1.10	1.05	1.05	1.05	1.05	1.05
		MPG*	2.00	2.30	2.50	3.00	3.20	3.40	3.40

* Gasoline equivalent

Stationary Fuel Cells

Tables 4 and 5 present the assumptions used in the stationary fuel cell characterization for GPRA05. The assumptions for distributed PEM fuel cells are based on the program's multiyear program plan (MYPP) (Ref 1.). Capital costs and efficiencies were provided in the MYPP for the years 2003, 2005, and 2010. The MYPP costs are assumed to be in year 2003 dollars, because the report was written in 2003 and no cost year is provided in the document. No values were listed for maintenance costs, so the AEO2003 values are used. Values were estimated to 2020. These values were then held constant post-2020 to 2050.

The AEO2003 values are used for the GPRA05 Baseline and are provided in year 2000 dollars.

There are no changes from the Baseline for large central-station fuel cells.

Table 4. 200 kW Commercial Combined Heat and Power Systems

Baseline AEO2003 Assumptions

First Year	Last Year	CHP System Efficiency	Electrical Efficiency	Thermal Recovery Efficiency	Equip. Cost (2000 $/kW)	Maint. Cost (2000$/kW-yr)
1993	2001	.729	0.360	0.577	3674	87.0
2002	2005	.731	0.378	0.567	3282	84.5
2006	2009	.733	0.401	0.554	2834	81.6
2010	2014	.736	0.430	0.536	2329	78.3
2015	2019	.740	0.473	0.506	1713	74.3
2020	2025	.741	0.495	0.488	1433	72.5

GPRA Program Assumptions

First Year	Last Year	CHP System Efficiency	Electrical Efficiency	Thermal Recovery Efficiency	Equip. Cost (2003 $/kW)[2]	Maint. Cost (2000$/kW-yr)
2002	2004	.700	0.300	0.571	2500	84.5
2005	2009	.750	0.320	0.632	1250	81.6
2010	2014	.800	0.400	0.667	750	78.3
2015	2019	.800	0.400	0.667	750	74.3
2020	2025	.800	0.400	0.667	750	72.5

Table 5. 5 kW Residential Combined Heat and Power Systems

Baseline AEO2003 Assumptions

First Year	Last Year	CHP System Efficiency	Electrical Efficiency	Thermal Recovery Efficiency	Equip. Cost (2000 $/kW)	Maint. Cost (2000$/kW-yr)
1993	2001	.729	0.360	0.577	3674	87.0
2002	2005	.731	0.378	0.567	3282	84.5
2006	2009	.733	0.401	0.554	2834	81.6
2010	2014	.736	0.430	0.536	2329	78.3
2015	2025	.740	0.473	0.506	1713	74.3

GPRA Program Assumptions

First Year	Last Year	CHP System Efficiency	Electrical Efficiency	Thermal Recovery Efficiency	Equip. Cost (2003 $/kW)[2]	Maint. Cost (2000$/kW-yr)
2002	2004	.700	0.300	0.571	3000	84.5
2005	2009	.750	0.320	0.632	1500	81.6
2010	2014	.800	0.350	0.692	1000	78.3
2015	2025	.800	0.350	0.692	1000	74.3

[2] Source: HFCIT Program's multiyear program plan. Costs are assumed to be in year 2003 dollars.

Hydrogen Price

In NEMS-GPRA05, the hydrogen price is computed as a function of natural gas prices because the model does not represent hydrogen production explicitly. Based on the MYPP, the hydrogen-conversion process is assumed to be 75% efficient and yield a hydrogen price of $1.50 (excluding taxes) when the natural gas price is $4 per MMBtu (Ref. 1).

In MARKAL-GPRA05, hydrogen cost estimates were developed for H2 produced using several centralized production processes (coal, natural gas, biomass, and electrolysis) as well as by distributed natural gas. A discussion of these estimates can be found in **Chapter 5** of the GPRA FY2005 Benefits Report, as well as in Reference 2.

Hydrogen Supply Technology Assumptions

Table 6 shows projected hydrogen costs by cost component for the Hydrogen Scenario, as presented in Reference 2. Please note that the projected costs may not match HFCITP goals due to differences in discount rates, distribution costs, taxes, and delivered feedstock costs.

Table 6. Hydrogen Production Costs by Technology and Component

Central Coal

Unit Costs (2001$/gge)	2015	2020	2025	2030	2035	2040	2045	2050
Capital Costs			$0.48	$0.48	$0.48	$0.48	$0.48	$0.48
O&M			$0.27	$0.27	$0.27	$0.27	$0.27	$0.27
Feedstock Costs			$0.22	$0.24	$0.25	$0.27	$0.27	$0.28
Plant Gate			**$0.97**	**$0.99**	**$0.99**	**$1.01**	**$1.02**	**$1.02**
Distribution, Storage & Tax			$1.03	$1.03	$1.03	$1.03	$1.03	$1.03
Total			**$2.00**	**$2.02**	**$2.03**	**$2.04**	**$2.05**	**$2.06**

Distributed Natural Gas Reformer

Unit Costs (2001$/gge)	2015	2020	2025	2030	2035	2040	2045	2050
Capital Costs	$0.73	$0.42	$0.42	$0.42	$0.42			
O&M	$0.53	$0.54	$0.53	$0.54	$0.54			
Feedstock Costs	$0.79	$0.83	$0.84	$0.90	$0.93			
Plant Gate	**$2.05**	**$1.79**	**$1.80**	**$1.86**	**$1.89**			
Tax	$0.38	$0.38	$0.38	$0.38	$0.38			
Total	**$2.43**	**$2.17**	**$2.17**	**$2.24**	**$2.27**			

Central Natural Gas Reformer

Unit Costs (2001$/gge)	2015	2020	2025	2030	2035	2040	2045	2050
Capital Costs			$0.15	$0.15	$0.15	$0.15	$0.15	
O&M			$0.08	$0.08	$0.08	$0.08	$0.08	
Feedstock Costs			$0.80	$0.86	$0.89	$0.93	$0.97	
Plant Gate			**$1.04**	**$1.10**	**$1.13**	**$1.17**	**$1.21**	
Distribution, Storage & Tax			$1.03	$1.03	$1.03	$1.03	$1.03	
Total			**$2.07**	**$2.13**	**$2.16**	**$2.20**	**$2.24**	

Central Biomass

Unit Costs (2001$/gge)	2015	2020	2025	2030	2035	2040	2045	2050
Capital Costs		$1.16	$1.02	$0.98	$0.96	$0.95	$0.95	$0.95
O&M		$0.34	$0.31	$0.31	$0.31	$0.31	$0.31	$0.31
Feedstock Costs		$0.35	$0.32	$0.32	$0.32	$0.32	$0.32	$0.32
Plant Gate		**$1.85**	**$1.65**	**$1.61**	**$1.59**	**$1.58**	**$1.58**	**$1.58**
Distribution & Storage*		$0.65	$0.65	$0.65	$0.65	$0.65	$0.65	$0.65
Total		**$2.50**	**$2.31**	**$2.26**	**$2.25**	**$2.24**	**$2.23**	**$2.23**

Central Electrolytic Production**

Unit Costs (2001$/gge)	2015	2020	2025	2030	2035	2040	2045	2050
Capital Costs		$0.12	$0.12	$0.12	$0.12	$0.12	$0.12	$0.11
O&M		$0.19	$0.19	$0.19	$0.19	$0.19	$0.19	$0.19
Feedstock Costs		$2.06	$2.02	$1.99	$2.31	$2.30	$2.21	$1.87
Plant Gate		**$2.37**	**$2.32**	**$2.30**	**$2.61**	**$2.60**	**$2.52**	**$2.17**
Distribution, Storage & Tax		$1.03	$1.03	$1.03	$1.03	$1.03	$1.03	$1.03
Total		**$3.41**	**$3.36**	**$3.33**	**$3.64**	**$3.64**	**$3.55**	**$3.20**

* Note: Hydrogen produced from biomass was assumed to receive preferential tax treatment.

** Central electrolytic production technologies did not penetrate in the Hydrogen Scenario case. The above costs are based on a separate model run where this technology was required to produce.

Hydrogen Availability

In NEMS-GPRA05, an availability factor for hydrogen refueling stations is required. The program provided the assumptions in **Table 7**. MARKAL-GPRA05 does not require or use this availability factor.

Table 7. Hydrogen Fuel Availability at US Stations (%)

	2005	2010	2015	2020	2025	2030	2035	2040
Hydrogen availability	0	0	0	10	25	30	40	50

References

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. P. Friley, “Benefit Estimation In MARKAL” (2004).