# Appendix G – GPRA06 Hydrogen, Fuel Cells, and Infrastructure Technologies (HFCIT) Program

## 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. Each 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.

### 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.

Non-vehicle 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. 1-3). The PSAT model is a simulation model used by DOE to evaluate the fuel economy and performance of light vehicles using various technologies. 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.) Other attributes were based on a review of past GPRA characterizations (e.g., Ref. 4).

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. **Table 1** contains the vehicle attributes for FCVs provided for input to the NEMS model. Attributes are provided for two car size classes and five light-truck classes. NEMS uses six car size classes and six light-truck classes, but for the NEMS analysis of FCVs to 2025 fewer classes were deemed sufficient.

**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 and Availability at Stations

Hydrogen price and availability assumptions are discussed in **Chapters 4 and 5** in the HFCIT Program sections.

### 1.3.3 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 4** (NEMS) and **Chapter 5** (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. Phillip Sharer and Aymeric Rousseau, "Fuel Economy of Advanced Technology Vehicles" for Phil Patterson, DOE (June 17, 2004).

3. Payback model developed by Jim Moore, TA Engineering (2003).

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

## Table 1. FCV Attributes Input to NEMS

| | SMALL CARS | | LARGE CARS | | | Small-VAN and SUV | |
|---|---|---|---|---|---|---|---|
| **Fuel Cell Hydrogen** | **2022** | **2025** | **2018** | **2023** | **2025** | **2020** | **2025** |
| Incremental Vehicle Price | 2010 | 1605 | 2264 | 1582 | 1477 | 2462 | 1640 |
| Range | 0.90 | 0.96 | 1.00 | 1.00 | 1.00 | 0.90 | 1.0 |
| Maintenance Cost | 1.05 | 1.02 | 1.05 | 1.00 | 0.97 | 1.10 | 1.00 |
| Acceleration | 1.00 | 1.06 | 1.00 | 1.00 | 1.04 | 1.00 | 1.10 |
| Top Speed | 0.90 | 0.93 | 0.85 | 0.90 | 0.92 | 0.90 | 0.95 |
| Luggage Space | 0.80 | 0.86 | 0.90 | 1.00 | 1.00 | 0.90 | 0.95 |
| Fuel Economy (a) | 2.54 | 2.56 | 2.54 | 2.80 | 2.89 | 2.49 | 2.57 |

| | Large-VAN and SUV | | | | CARGO TRUCK | |
|---|---|---|---|---|---|---|
| **Fuel Cell Hydrogen** | **2012** | **2018** | **2023** | **2025** | **2024** | **2025** |
| Incremental Vehicle Price | 4500 | 3140 | 2086 | 1975 | 2886 | 2656 |
| Range | 0.90 | 1.00 | 1.00 | 1.00 | 0.90 | 0.93 |
| Maintenance Cost | 1.10 | 1.05 | 1.00 | 0.97 | 1.05 | 1.04 |
| Acceleration | 1.00 | 1.10 | 1.10 | 1.10 | 1.00 | 1.00 |
| Top Speed | 0.90 | 0.90 | 0.95 | 0.95 | 0.90 | 0.90 |
| Luggage Space | 0.90 | 0.95 | 1.00 | 1.00 | 0.90 | 0.91 |
| Fuel Economy (a) | 2.00 | 2.49 | 2.57 | 2.73 | 2.49 | 2.51 |

(a) Gasoline gallon equivalent

## Table 2.  FCV Attributes Input to MARKAL

| Vehicle Type | Technology | Ratio | 2010 | 2015 | 2020 | 2025 | 2030 | 2040 | 2050 |
|---|---|---|---|---|---|---|---|---|---|
| Car | Fuel Cell | Cost | | 1.15 | 1.07 | 1.06 | 1.05 | 1.045 | 1.4 |
| | | MPG (a) | | 2 | 2.54 | 2.8 | 3.03 | 3.03 | 3.03 |
| LT | Fuel Cell | Cost | | 1.15 | 1.07 | 1.06 | 1.05 | 1.045 | 1.04 |
| | | MPG (a) | | 2 | 2.49 | 2.57 | 2.96 | 2.96 | 2.96 |

(a)  Gasoline gallon equivalent

## 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

The technology assumptions for distributed generation, including stationary fuel cells, were updated in AEO2004. A review of these assumptions revealed a few definitional differences in how the HFCIT Program goals are stated and how the technology characterizations are used within NEMS. There also appeared to be 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 AEO2004 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**

| Year | CHP System Efficiency | Electrical Efficiency | Installed Cost (2003 $/kW) | Maint. Cost (2003$/kW-yr) |
|---|---|---|---|---|
| **AEO2004 Reference Case** | | | | |
| 2003 | 0.690 | 0.300 | 5500 | 264 |
| 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 |
| **GPRA06 Baseline** | | | | |
| 2003 | 0.630 | 0.270 | 3800 | 264 |
| 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

**AEO2004 Reference Case**

| Year | CHP System Efficiency | Electrical Efficiency | Installed Cost (2003 $/kW) | Maint. Cost (2003$/kW-yr) |
|---|---|---|---|---|
| 2003 | 0.750 | 0.360 | 5200 | 232 |
| 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 |

**GPRA06 Baseline**

| | | | | |
|---|---|---|---|---|
| 2003 | 0.630 | 0.270 | 3180 | 232 |
| 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 2003, 2005, and 2010. The costs are assumed to be in year 2003 dollars. No values were listed for maintenance costs, so the AEO2004 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) |
|---|---|---|---|---|
| 2003 | 0.70 | 0.30 | 3000 | n/a |
| 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) |
|---|---|---|---|---|
| 2003 | 0.630 | 0.270 | 3800 | 264 |
| 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) |
|---|---|---|---|---|
| 2003 | 0.70 | 0.30 | 2500 | n/a |
| 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) |
|---|---|---|---|---|
| 2003 | 0.630 | 0.270 | 3180 | 232 |
| 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 |

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

## 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).