# VII.A.3 Fuel Cell Electric Truck (FCET) Component Sizing

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## Overall Objectives

- Understand the range and performance capabilities of FCETs.
- Develop design concepts that are functionally equivalent to conventional internal combustion engine powered trucks, for multiple classes and vocations.
- Analysis aims to reveal:
  - Fuel cell and battery power required for trucks.
  - Stored hydrogen weight and total weight of the fuel cell system.
  - Fuel economy and range expected from FCETs.
  - Whether the concept designs meet real-world requirements.

## Fiscal Year (FY) 2016 Objectives

- Develop component sizing logic for FCETs.
- Demonstrate the design feasibility of fuel cell-dominant trucks.

## Technical Barriers

This project addresses the following technical barriers from the Technology Validation section of the Fuel Cell Technologies Office Multi-Year Research, Development, and Demonstration Plan.

(A) Lack of Fuel Cell Electric Vehicle and Fuel Cell Bus Performance and Durability Data

(C) Hydrogen Storage

## Contribution to Achievement of DOE Technology Validation Milestones

This project will contribute to achievement of the following DOE milestones from the Technology Validation section of the Fuel Cell Technologies Office Multi-Year Research, Development, and Demonstration Plan.

- Validate fuel cell electric vehicles achieving 5,000-hour durability (service life of vehicle) and a driving range of 300 miles between fuelings. (4Q, 2019)

## FY 2016 Accomplishments

- Developed a generic powertrain sizing logic for FCETs, aimed to meet performance targets derived from comparable conventional trucks.
- Developed models for 12 medium- and heavy-duty vehicles from various classes and vocations. This will serve as a reference for multiple DOE-funded activities.
- Estimated the component power requirement for fuel cell, battery, and electric machine to be used in medium- and heavy-duty applications.
- Estimated the onboard hydrogen storage requirement.

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## INTRODUCTION

This study examines the suitability of converting a representative sample of medium- and heavy-duty diesel trucks into FCETs, while ensuring similar truck performance, in terms of range, payload, acceleration, speed, gradeability, and energy consumption. The large number of truck body types, weight classes, and vocational uses results in a large potential design space. Each class and vocation has unique functional requirements that determine specific design choices.

To capture the medium-duty and heavy-duty markets, candidate truck classes and vocations were identified by their recent market size using the Vehicle Inventory and Use Survey [1]. The list spans nearly all classes and many vocations, and is shown in Table 1. Baseline trucks were selected for each candidate class and vocation based on their market share. Some of these choices span multiple weight classes and are popular in multiple vocations. Truck manufacturers design these trucks with requirements arising from a variety of use cases. When such trucks are converted to FCETs, it is important to ensure that functional capabilities are not sacrificed.

**TABLE 1.** Overview of the Weight Classes and Vocations Considered in this Study

| Vehicle Class | Weight | Vocation/Description |
|---|---|---|
| Class 2b | 6,000–10,000 lb | Small van |
| Class 3 | 10,001–14,000 lb | Enclosed van |
| Class 3 | 10,001–14,000 lb | School bus |
| Class 3 | 10,001–14,000 lb | Service, utility truck |
| Class 4 | 14,001–16,000 lb | Walk-in, multi-stop, step van |
| Class 5 | 16,001–19,500 lb | Utility, tow truck |
| Class 6 | 19,501–26,000 lb | Construction, dump truck |
| Class 7 | 26,001–33,000 lb | School bus |
| Class 8 | 33,001 lb or heavier | Construction, dump truck |
| Class 8 | 33,001 lb or heavier | Line haul |
| Class 8 | 33,001 lb or heavier | Refuse, garbage pickup, cab over type |
| Class 8 | 33,001 lb or heavier | Tractor trailer |

## APPROACH

The baseline truck models were developed based on data available from manufacturers and third parties [2]. Autonomie was used to perform the vehicle simulations because of its existing validated models. To demonstrate the design and simulation process, this report focuses on a Class 4 delivery van as an example. It is possible to calculate important vehicle performance characteristics that are directly related to the powertrain's capabilities. This is done by benchmarking the baseline vehicle model. The parameters characterizing vehicle performance for this process are shown in Table 2. The goal of the FCET sizing process is to ensure that the fuel cell powered vehicle can match or better these performance results.

**TABLE 2.** Benchmark Values for the Class 4 Delivery Van

| Performance Criteria | Baseline |
|---|---|
| Cargo Mass (lb) | 5,280 |
| Cruising Speed (mph) | 70 |
| Grade Speed (mph) | 50 |
| 0–30 mph acceleration time (s) | 7.2 |
| 0–60 mph acceleration time (s) | 29.8 |

## RESULTS

The FCET considered in this study is a hybrid vehicle that uses a fuel cell as its primary source of energy. The battery is sized to assist the fuel cell during high-power transient operations and is also used for regenerative braking. The major components that are being sized in this study include the electric machine, battery, fuel cell, and overall gear ratio. This sizing logic is used to estimate the power required for each of the performance tests. This example shows the sizing results for a Class 4 pickup and delivery vehicle.

**TABLE 3.** Results of the Motor Power and Final Drive Sweep Test

| Selected Component | Size |
|---|---|
| Motor Continuous Power (kW) | 151 |
| Motor Rated Power (kW) | 260 |
| Fuel Cell Power (kW) | 164 |
| Battery Power (kW) | 54 |
| Battery Total Energy (Wh) | 1,426 |
| Battery Volume (L) | 53.4 |
| Motor Speed Ratio | 8.9 |

The FCET component specification that was sized using the methodology described in this study met all the vehicle requirements within the desired tolerance of 2%. The designed vehicle can carry the same cargo, meet the grade and cruise performance of the baseline vehicle, and significantly exceed the acceleration performance requirements. These vehicles, which were tested on real world drive cycles from the National Renewable Energy Laboratory's FleetDNA database, met most real world driving requirements for all vocations other than line-haul applications. The driving range requirement for line-haul is currently fixed at 400 mi, but real world driving shows that many vehicles drive more than that distance in a trip. It is not clear from the driving data whether they have refueling stops. Other than this specific case, we find that the FCETs can match the real world daily driving requirements for other classes and vocations.

Similar analysis on other vehicle classes yielded the fuel cell and onboard hydrogen storage requirement shown in Figure 1. This shows that a 180-kW fuel cell and approximately 15 kg of onboard hydrogen storage could satisfy the need of many medium- and heavy-duty vocations. This could serve as a component target for future development work.

## CONCLUSIONS AND FUTURE DIRECTIONS

This study puts forth a preliminary process to estimate the component sizes of a fuel cell powered electric truck that would be necessary to meet the functional requirements of a reference baseline vehicle. It accounts for the weight difference due to component changes, and the feasibility of finding the necessary volume for the hydrogen tanks. This report used Class 4 trucks as an example, but similar analysis


**FIGURE 1.** Fuel Cell and Hydrogen Tank Sizing Result for FCETs

was performed for additional classes and vocations. The analysis demonstrated that there are no major technological hurdles to meeting the performance requirements for trucks with hydrogen and fuel cell systems.

Cost and durability have not been considered, but they may present challenges until markets are established and economies of scale reduce the cost of producing fuel cell systems. The vehicle use cases were compared against national surveys and against data collected from major fleet operators. The next step will be to add the ownership cost component into this study to examine the economic feasibility of these vehicles. This would also look at the impact of component sizing on energy consumption, and the tradeoff between initial cost and ownership costs.

## FY 2016 PUBLICATIONS/PRESENTATIONS

**1.** Marcincoski, J., Vijayagopal, R., Kast, J., Duran, A., 2016. "Driving an Industry: Medium and Heavy Duty Fuel Cell Electric Truck Component Sizing." Paper presented at Electric Vehicle Symposium, Montreal, Canada, June 2016.

**2.** Kast J., Vijayagopal, R., Gangloff,J., Marcincoski, J. 2016. "Clean Commercial Transportation: Medium and Heavy Duty Fuel Cell Electric Truck Targets." Paper presented at World Hydrogen Energy Conference, Zaragoza, Spain, June 2016.

## REFERENCES

**1.** U.S. Census Bureau. 2002. "Vehicle Inventory and Use Survey." Accessed June 24, 2015 http://www.census.gov/svsd/www/vius/2002.html.

**2.** "2014 Truck Index," Truck Index, Inc., Santa Ana.