U.S. DEPARTMENT OF ENERGY

Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

DOE H_2 Heavy Duty Truck Targets

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Compressed Gas Storage for Medium and Heavy Duty Transportation Workshop

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Overview

- DOE Released H_2 Class 8 Long Haul Truck Targets in December 2019
- Program Record #: 19006
- www.hydrogen.energy.gov/pdfs/19006_hydrogen_class8_long_haul_truck_targets.pdf
- First Attempt – we plan to regularly look at these and revise as appropriate, so all feedback is welcome

Objectives of the Targets

Specific
Measurable
Achievable
Relevant
Time-bound

- **Targets aim for competitive technology in 2030 to 2050 timeframe**
- Inform and guide R&D activities
- **Vehicle level targets flow down to components**
  - Fuel Cells (Efficiency, vehicle life, and cost targets)
    - Membranes, catalysts, bipolar plate, balance of plant, thermal management
  - **Storage (Cost, fill rate and cycle life targets)**
    - **Storage type, materials, geometry, energy density, balance of plant**
  - Infrastructure (fill rate)
    - H_2 compressors, pumps, hoses, nozzles, chillers
- **Subprogram targets TBD (guided by vehicle level targets)**
  - **i.e., What storage system capacities should we target?**

Overall Process

- **June 2016** - RFI
- **July 2018** - Workshop at ANL
  - Key participants:
    - Toyota, Nikola, FedEx, UPS, CTE, Eaton, Cummins, Trillium, Air Liquide, Air Products, Proton Onsite, Hydrogenics, Ballard, Hexagon, NREL, ANL
- **December 2018** - Presentation to 21st Century Truck Executive Team
- **February 2019** – Vehicle Technologies Office review
- **May 2019** – Targets sent out for external review to key stakeholders
- **May 2019** – Presentations to 21st Century Truck IC Powertrain and Electrification Tech Teams
- **June 2019** – Revisions sent out for review
- **December 2019** – Posted

Key Assumptions

- 1.2 million mile vehicle life
- 750 mile range (600 mile interim range)
- 12.4 miles/kg fuel economy (11.1 miles/kg interim)
  - Current status ~10 miles/gallon of diesel[1]
- 40 mph average speed
  - Lifetime: 50% long haul, 50% regional
- End of Life = 10% voltage degradation for benchmarking purposes
- Interim fuel cell lifetime targets were set to ~80% of the Ultimate fuel cell lifetime targets
- Hotel loads will likely be supplied by the battery pack using the fuel cell for charging (e.g. <10 min. fuel cell use every 500 miles). With this strategy hotel loads require < 200 hrs. over the first 500,000 miles.

[1] Run-On-Less Report, North American Council for Freight Efficiency, Feb 28, 2018, https://nacfe.org/run-on-less-report/

System Targets: Class 8 Tractor-Trailers

Characteristic	Units	Targets for Class 8 Tractors-Trailers	
		Interim (2030)	Ultimate[9]
Fuel Cell System Lifetime[1,2]	[hours]	**25,000**	**30,000**
Fuel Cell System Cost[1,3,4]	[$/kW]	**80**	**60**
Fuel Cell Efficiency (peak)	[%]	**68**	**72**
Hydrogen Fill Rate	[kg H_2/min]	**8**	**10**
Storage System Cycle Life[5]	[cycles]	**5,000**	**5,000**
Pressurized Storage System Cycle Life[6]	[cycles]	**11,000**	**11,000**
Hydrogen Storage System Cost[4,7,8]	[$/kWh] ($/kg H_2 stored)	**9** **(300)**	**8** **(266)**

1 The fuel cell system excludes hydrogen storage, power electronics, batteries, and electric drive.

2 The lifetime target is intended to cover the entire useful life of the vehicle. Fuel cell system life time is defined as hours of use with an appropriate duty cycle that considers real world driving conditions (i.e. not steady state operation). Corresponding vehicle lifetime range is 1M miles (Interim) and 1.2M miles (Ultimate) based on an average speed of 40 mph.

3 Interim and ultimate cost targets assume 100,000 units per year production volumes (except where specified within parenthetical references). Note that meeting fuel cell and hydrogen storage component cost targets may require leveraging automotive production volumes to achieve the necessary economies of scale for cost competitiveness. Current (2019) heavy duty vehicle fuel cell technology was estimated to cost ~$190/kW at 1,000 units per year manufacturing volume (Fuel Cell Systems Analysis, 2019 DOE Hydrogen and Fuel Cells Program Review Presentation, https://www.hydrogen.energy.gov/pdfs/review19/fc163_james_2019_o.pdf).

4 Costs are in 2016 dollars.

5 The storage system cycle life target is intended to represent the minimum number operational cycles required for the entire useful life of a vehicle used in long-haul operation. This target is technology agnostic.

6 Pressurized storage systems must meet cycle life requirements in applicable codes and standards (i.e. SAE J2579 and United Nations Global Technical Regulation No. 13). These codes and standards cycle life requirements require significantly more cycles than Storage System Cycle Life. For example, the baseline initial pressure cycle life in the United Nations Global Technical Regulation can require 11,000 cycles for a heavy duty application.

7 Hydrogen storage system cost includes the storage tank and all necessary balance-of-plant components. This target is technology agnostic.

8 Current (2019) 700 bar hydrogen storage system was estimated to cost ~$36/kWh at 1,000 units per year manufacturing volume and $15/kWh at high volume (extrapolated from DOE Hydrogen and Fuel Cells Program Record #15013 "Onboard Type IV Compressed Hydrogen Storage System - Cost and Performance Status 2015, "https://www.hydrogen.energy.gov/pdfs/15013_onboard_storage performance cost.pdf). Note: Hydrogen Storage Targets will be updated and are currently based on USDRIVE FCEV targets.

9 Analysis based on 2050 simple cost of ownership assumptions and reflects anticipated timeframe for market penetration.

Fuel Cell Related Targets

Characteristic	Units	Targets for Class 8 Tractors-Trailers	
		Interim (2030)	Ultimate
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Exceeded DOE-DOT Fuel Cell Bus Durability Target

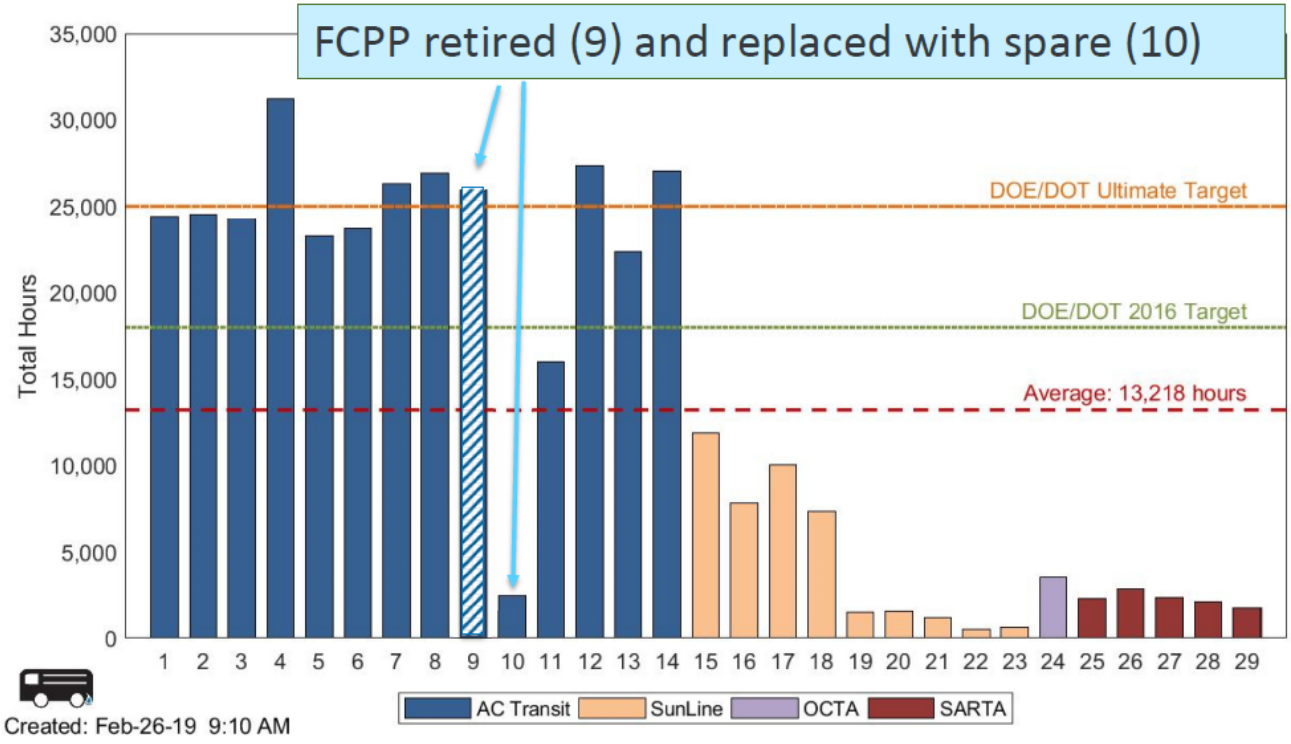
(However Durability, Cost and Efficiency Metrics Need to be Met Simultaneously)

Top fuel cell bus runs

>31,200 hours,

surpassing DOE/DOT ultimate target

6 fuel cell buses have more than **25,000 hours**



Total hours accumulated on each FCPP as of 12/31/18

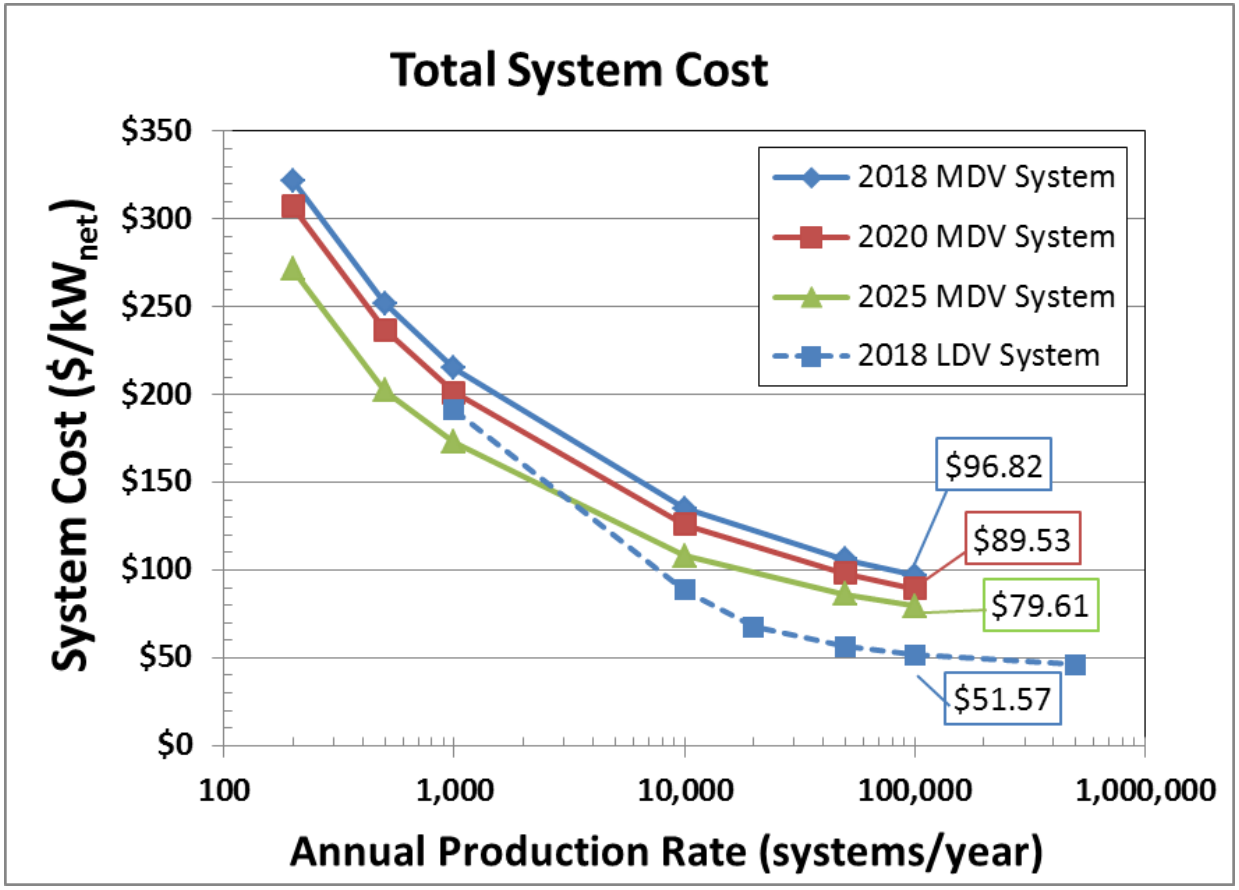
Current FC System Costs

(M/HD stacks likely to require higher Pt loading / alterative stack designs to meet durability targets)

Conventional Diesel engine is ~$25,000 (including catalytic & particulate filters, etc)

390 kW fuel cell system needed to meet 440 HP diesel performance by ANL

$60/kW Ultimate target = $23,400



Storage Related Targets

Characteristic	Units	Targets for Class 8 Tractors-Trailers	
		Interim (2030)	Ultimate
Hydrogen Fill Rate	[kg H_2/min]	**8**	**10**
Storage System Cycle Life[5]	[cycles]	**5,000**	**5,000**
Pressurized Storage System Cycle Life[6]	[cycles]	**11,000**	**11,000**
Hydrogen Storage System Cost[4,7,8]	[$/kWh] ($/kg H_2 stored)	**9** **(300)**	**8** **(266)**

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Storage Related Targets – Fill Rate

Characteristic	Units	Targets for Class 8 Tractors-Trailers	
		Interim (2030)	Ultimate[9]
Hydrogen Fill Rate	[kg H_2/min]	**8**	**10**

Ultimate Goal: 10 kg/min

- 6 minutes to fuel 60 kg (10 kg/min)
- 60 kg would equate to ~750 miles assuming fuel economy of 12.4 miles/kg

Interim Goal: 8 kg/min - still allows for:

- >750 mile range
  - 10 minute fill
  - fuel economy of 11.1 miles/kg
- ~600 mile range
  - 6 minute fill
  - fuel economy of 12.4 miles/kg

Storage Related Targets – Cycle Life

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5,000 Cycles to Meet Vehicle Life of 1.2M miles

- Assume tanks filled at ¼ tank of fuel
- ¼ tank = 560 miles per cycle
- 1,200,000 / 560 = ~2,150 fills
- Target set at 5,000 cycles to account for vehicles that extend beyond their expected lifetime or are fueled more frequently

11,000 Cycles for Pressurized Tanks to Ensure Safety

- Pressurized hydrogen storage tanks must meet applicable codes and standards (i.e., SAE J2579 and the United Nations Global Technical Regulation No. 13) to ensure safe performance
- These codes contain significant detail / nuances specific to cycle requirements for pressurized tanks to ensure their safe operation

Storage Related Targets – System Cost

Characteristic	Units	Targets for Class 8 Tractors-Trailers	
		Interim (2030)	Ultimate[9]
Hydrogen Storage System Cost[4,7,8]	[$/kWh] ($/kg H_2 stored)	**9** **(300)**	**8** **(266)**

- Targets based on existing LDVs targets
  - LDVs targets assume 500,000 units/yr and 1 or 2 tank(s) per vehicle
  - HD targets only assume 100,000 units/yr, but several tanks per HD truck
  - LDVs targets assume 5.6 kg usable H_2 tanks
  - HD likely >5.6 kg H_2; Large tanks likely lower cost on a $/kWh or $/kg H_2 basis
    - Amount of CF and BOP per kg H_2 is likely to be less
- DOE is currently conducting cost analysis (SA / ANL) of HD storage systems; targets may get updated accordingly
- List of assumptions for LDV storage system cost can be found here:

  https://www.energy.gov/sites/prod/files/2017/05/f34/fcto_targets_onboard_hydro_storage_explanation.pdf

System Cost - Simple Total Cost of Ownership check

Class 8 Long Haul	Diesel Status (2019)	Hydrogen Status (2019)	Diesel 2050	Hydrogen 2050
Fuel Cost ($/gal diesel or $/kg H2)	2.78	16	4.09	5.00
Fuel Economy (mpg or mpkg)	10	11	15.6	17.0
Lifetime Fuel Cost	$ 278,000	$ 1,496,000	$ 315,000	$ 353,000
Total Tractor Cost	$ 134,000	$ 266,000	$ 131,000	$ 129,000
Lifetime Fuel and Capital Cost	**$ 412,000**	**$ 1,762,000**	**$ 446,000**	**$ 482,000**
Fuel Cost ($/mile)	*$ 0.28*	*$ 1.50*	*$ 0.26*	*$ 0.29*
Tractor Cost ($/mile)	*$ 0.13*	*$ 0.27*	*$ 0.11*	*$ 0.11*
Maintenance Cost ($/mile)	*$ 0.17*	*$ 0.25*	*$ 0.17*	*$ 0.17*
Total Fuel and Capital Cost ($/mile)	**$ 0.58**	**$ 2.0**	**$ 0.54**	**$ 0.57**

- Only considers upfront capital cost and lifetime fuel cost (doesn't include financing, change in fuel cost over vehicle life, or tax credits); in 2018 dollars
- All non-powertrain improvements (e.g. aerodynamics, light weighting, driveline, accessory efficiency) are the same between powertrains
- Diesel cost based on projected values rom EIA 2018 Annual Energy Outlook; status (2019) fuel cost = $2.78/gal; 2050 fuel cost = $4.09/gal
- Assumes $5/kg for cost of H_2 dispensed at the pump (DOE cost target for H_2 is $4/kg)
- Assumed costs for 2050 scenario: (battery $1,500, electric motor and power electronics $4,500 [2x the light duty vehicle traction motor & power electronics targets of $6/kW], vehicle chassis $75,000, diesel engine with emissions after treatment $20,000, transmission $8,700, waste heat recovery system $5,000). A simplified 20% markup is applied across all components.

Thank You!

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