DOE Alternative Fuels and Feedstocks Office Program Record

Record #: 26002 **Date:** 05/14/2026

Title: Heavy-Duty Fuel Cell System Cost – 2024

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Item:

The cost of a 275-kW_{net} proton exchange membrane (PEM) fuel cell system based on 2024-status next-generation laboratory technology[1] and operating on direct hydrogen is projected to be \$155/kW_{net} when manufactured at a volume of 50,000 units/year (~\$146/kW_{net} when manufactured at a volume of 100,000 units/year). The current industrial manufacturing capacity baseline is <1,000 systems/year at approximately \$282 per kW_{net}. The analysis centered on a fuel cell system optimized for a Class 8 long-haul heavy-duty (HD) truck application, though such systems have multi-modal applications and are currently being developed for stationary power for data centers. These costs include design aspects for enhanced durability projected to achieve one million miles (25,000 hours) of fuel cell system performance needed for heavy-duty long-haul trucks.[2] Durability assumptions include stack oversizing (allowing for fuel cell degradation), monometallic Pt cathode catalyst, 15-micron thick membrane, and balance-of-plant (BOP) replacement costs. Key differences between the 2023[3] and 2024 systems are 1) a reduction in Pt loading (from 0.45 to 0.35 mg Pt/cm^2, total) while maintaining the same performance and durability, 2) a reduction in membrane thickness (from 20 to 15 microns) that aligns with industry offerings and industry feedback, 3) a 30% increase in ionomer, ePTFE, and gas diffusion layer (GDL) prices to reflect industry feedback,[4] and 4) a reduction in the balance-of-plant (BOP) replacement cost from 35% to 27% of total BOP cost.[5]

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[1] The projected cost status is based on an analysis of state-of-the-art components that have been developed and demonstrated through HFTO at the laboratory scale. Additional efforts would be needed for integration of components into a complete commercial vehicle system that meets durability requirements in real-world conditions. Unless otherwise noted, all costs in this report are in 2020\$.

[2] Marcinkoski, J., "Hydrogen Class 8 Long Haul Truck Targets," DOE Hydrogen Program Record# 19006, 2019. https://www.hydrogen.energy.gov/pdfs/19006_hydrogen_class8_long_haul_truck_targets.pdf

[3] DOE Hydrogen Program Record 24004: Heavy-Duty Fuel Cell System Cost – 2023

[4] At 50k systems per year, ionomer price: \$658/kg at 95 MT/year, ePTFE price: \$9.68/m^2 at 3.2M m^2/year, and GDL price: \$8.48/m^2 at 5.3M m^2/year.

[5] Re-evaluation of both components for replacement, number of replacements, and labor. BOP replacement cost includes nine air filter and coolant ion exchange filters, and single component replacement for the humidifier and H_2

Rationale:

The U.S. Department of Energy (DOE) Alternative Fuels and Feedstocks Office (AFFO) within the Office of Critical Minerals and Energy Innovation (CMEI) supports projects that conduct detailed analyses to estimate the cost status of fuel cell systems on an annual basis. Strategic Analysis, Inc. (SA) conducted a cost analysis of a 275-kW_{net} direct hydrogen proton exchange membrane (PEM) heavy duty (HD) fuel cell system based on 2024 technology and a manufacturing volume of up to 100,000 units per year. **This analysis tracks technological progress, and readers should understand its assumptions and scope before comparing it to currently manufactured systems.** All costs reported in this record are in 2020 dollars to track the cost impact of technological improvements rather than the effects of inflation or volatility in material pricing. Pt is kept constant at its assumed value of $1,500 per troy ounce in 2020 dollars. The system cost represents a fuel cell manufacturer's price [cost to a truck original equipment manufacturer (OEM)] where vehicle OEM markup for profit, research and development (R&D), or corporate overhead are not included.[6] The key differences between the 2023 and 2024 systems are 1) a reduction in Pt loading (from 0.45 to 0.35 mg Pt/cm^2 , total) while maintaining the same performance and durability, 2) a reduction in membrane thickness (from 20 to 15 microns) that aligns with industry offerings and industry feedback, 3) a 30% increase in ionomer, ePTFE, and gas diffusion layer (GDL) prices to reflect industry feedback, and 4) a reduction in the BOP replacement cost from 35% to 27% of total BOP cost.

SA and Argonne National Laboratory (ANL) worked together to establish a representative system design and realistic stack operating conditions, based on industry input, that was used as the basis of the HD Class 8 truck system. Power system cost projections are based on end of life (EOL) stack performance. EOL occurs when the system performance drops below the intended commercial application's requirements (e.g., 275 kW_{net} for the long-haul Class 8 truck application), although the power system could still be used for less demanding applications. Durability aspects have been reviewed by experts[7] and include the following:

- 53 m^2 of active membrane area (total of two stacks) inclusive of 67% oversizing to account for MEA performance losses after 25,000 hours and targeted to achieve 275 kW_{net} at EOL
- Graphite bipolar plates (BPPs) were chosen for the 2024 baseline system as they have demonstrated >30,000 hours of bus operation.[8] Metallic BPPs are also used in industry but have not yet demonstrated 25,000 hours: operating conditions and coating selection are vital to achieve such a lifetime.

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recirculation pump over 25,000-hour operational lifetime. Labor was based on estimated hours and an hourly rate of $57/hour. This cost excludes markup for administrative or procurement costs and other costs beyond the component and labor costs for replacement. BOP replacement cost is added to the baseline system cost so as to track any improvements in the durability of these BOP components.

[6] The 2024 system cost is based on a non-vertically integrated markup structure where the fuel cell system manufacturer, powertrain system integrator, and truck OEM are all separate entities. Markup is included for the fuel cell system supplier and powertrain system integrator, but no markup is included for the truck OEM.

[7] System design based on input from the Million Mile Fuel Cell Truck consortium, the 21st Century Truck Partnership, and the U.S. DRIVE Fuel Cell Technical Team.

[8] https://www.ballard.com/wp-content/uploads/2024/10/2019-metal-vs-graphite-bipolar-plates-update.pdf

- Million Mile Fuel Cell Truck (M2FCT) consortium baseline catalyst: annealed Pt on high surface area carbon (a-Pt/HSC) cathode catalyst for enhanced durability[9]
- High platinum group metal (PGM) loading: 0.30 mg Pt/cm^2 on cathode, 0.05 mg Pt/cm^2 on anode, for enhanced durability[9]
- 15-micron thick ePTFE-supported perfluorosulfonic acid (PFSA) membrane
- The fuel cell system is envisioned to operate in a fuel cell-battery hybrid powertrain, wherein the battery is sized to provide 75 kWh useable energy at EOL (70% depth of discharge, 10% power degradation over lifetime) and 140 kW$_{net}$ of continuous power. Gradual improvements in battery technology are expected to facilitate enhanced fuel cell stack durability by enabling extended stack operation at conditions that minimize electrochemical surface area (ECSA) loss
- A replacement cost (equal to 27% of the BOP component cost) for some fuel cell-specific components to achieve 25,000 hours of BOP system lifetime
- 10% cost contingency for non-enumerated costs associated with durability and supply chain uncertainties.

To address durability and to design a system that meets the 25,000-hour power system lifetime requirement, a stack oversizing method was used rather than a stack replacement method.[10] In 2023, ANL determined the beginning of life (BOL) and EOL operating conditions for estimated degradation based on the extent of ECSA loss after 25,000 hours over a Class 8 long-haul highway drive cycle.[11] The 2024 system is sized to ensure 275 kW$_{net}$ at EOL and assumes the same ECSA loss, oversizing, and power density as the 2023 system. Importantly, the modeled ECSA loss only affects the extent of stack oversizing and does not impact the other durability aspects built into the system cost.

HD operating conditions for 2023 and 2024 systems are listed in Table 1. Note that this detailed definition of the HD vehicle (HDV) system is a relatively recent effort (over the last 5 years) compared to the more extensively studied light-duty vehicle (LDV) system (studied for over 15 years). Consequently, these HDV models are still evolving to fully capture real-world approaches and system designs.

ANL estimated that the 2023 HDV system could achieve 275 kW$_{net}$ operating at 0.7 V/cell at EOL and would lose 50% of the ECSA over 25,000 hours of run time. ANL's model estimates a

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[9] R. Borup, A. Weber, et al., "M2FCT: Million Mile Fuel Cell Truck Consortium," presented at the U.S. DOE Hydrogen Program 2023 Annual Merit Review and Peer Evaluation Meeting, Arlington, Virginia, June 2023. Accessed: February 29, 2024. https://www.hydrogen.energy.gov/docs/hydrogenprogramlibraries/pdfs/review23/fc339_weber_2023_o-pdf.pdf

[10] Feedback from the fuel cell community suggests that stack oversizing is a common method to extend the life of the fuel cell. Stack oversizing is a method to offset stack performance degradation by increasing stack active area above that necessary at beginning of life to achieve a targeted power production at end of life. In contrast, a replacement strategy would not oversize the stack (or at least not a full oversizing) but rather would replace the stack when power production fell to a threshold value.

[11] Ahluwalia, R., Wang, X., "Performance and Durability of Hybrid Fuel Cell Systems for Class-8 Long Haul Trucks," *Journal of the Electrochemical Society* 171 (2024): 034507. https://iopscience.iop.org/article/10.1149/1945-7111/ad300f/pdf

BOL peak system efficiency of 64.5% compared to the DOE target of 68% in 2030.[12] SA continues to use these performance estimates for the 2024 system, albeit achieved at a lower Pt loading. Using a lower Pt loading is intentional and based on feedback from industry that the targeted power density (642 mW/cm^2) was achievable with <0.4 $mgPt/cm^2$ cathode Pt loading. Additionally, promising catalysts are under review by the M2FCT and have preliminarily met M2FCT targets for Pt loading and power density.[13] The rate of ECSA loss over a long-haul truck drive cycle has not yet been verified by lab testing of the stack or validated through on-road testing. As there is uncertainty in stack durability, a 10% system cost contingency is added to the HD baseline cost to capture all unanticipated costs, inclusive of non-enumerated costs associated with durability.

Table 1. System design parameters at BOL and EOL for 2023[14], 2024[15] HD fuel cell systems

Characteristic (all values at rated power unless otherwise indicated)	**Units**	**2023 BOL[a]**	**2023 EOL**	**2024 BOL[a]**	**2024 EOL**
Net system power	kW_{net}	313	275	313	275
Gross stack power	kW_{gross}	376	338	375	337
Nominal system efficiency at rated power conditions[b] (at steady state)	%	56	50	56	50
Cell voltage[c]	V	0.78	0.70	0.78	0.70
Air stoichiometric ratio[c]		1.5	1.5	1.5	1.5
Stack inlet pressure[c]	atm	2.5	2.5	2.5	2.5
Stack exit coolant temp[c]	°C	90	90	90	90
Total PGM loading[c,d]	mg_{PGM}/cm^2	0.45	0.45	0.35	0.35
MEA areal power density	mW/cm^2	715	642	714	642
ECSA loss after 25,000 hours	%	--	50	--	50
Active area oversizing	%	67	67	67	67
Total active area	m^2	52.6	52.6	52.5	52.5
Number of stacks/system	#	2	2	2	2
$Q/\Delta T$[e]	kW/°C	4.5	5.3	4.5	5.3
Ambient temp. (for radiator sizing)	°C	40	40	40	40
Fuel cell system cost @ 50k/y (2023/2024 status) [f]	2020\$/ kW_{net}		173		155

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[12] During operation, the vehicle will spend most of the time between peak system efficiency (which occurs at ~25% rated power) and the rated power efficiency (which occurs at full rated power). 68% stack efficiency remains the long-term DOE target to promote technological advancement towards more efficient FC stacks. Current technology requires a tradeoff between durability and efficiency, with higher stack voltages (efficiency) coming at the expense of catalyst durability. Present fuel cell systems emphasize durability over maximum efficiency.

[13] 2.5 kW/gPGM power, <0.3$mgPt/cm^2$ at 750 mW/cm^2 (1.07A/cm^2 current density at 0.7 V) - after 25,000-hour equivalent accelerated durability test. See footnote 9.

[14] Assumptions and results for the 2023 system are documented in SA's 2023 Final Report: "Mass Production Cost Estimation of Direct H_2 PEM Fuel Cell Systems for Transportation Applications: 2023 Update on Heavy and Medium-Duty Vehicles," Brian D. James, Jennie M. Huya-Kouadio, Cassidy Houchins, Mark J. Jensen, and Kevin R. McNamara, Strategic Analysis, Inc., September 2023.

[15] Assumptions and results for the 2024 system are documented in SA's 2024 Final Report: "Mass Production Cost Estimation of Direct H_2 PEM Fuel Cell Systems for Transportation Applications: 2024 Update on Heavy-Duty, Medium-Duty, and Off-Road Mining Vehicles," Brian D. James, Jennie M. Huya-Kouadio, Cassidy Houchins, Mark J. Jensen, Kevin R. McNamara, and Timothy S. Duffy, Strategic Analysis, Inc., September 2024.

[a] Although the BOL stacks could produce a higher power with no ECSA loss, actual operation would be limited to 275 kW_{net} as the BOP components are sized for EOL gross power.

[b] The steady state efficiency at 275 kW (net rated power). Note that stack conditions in the table correspond to the conditions used to size the system for peak power and differ from conditions experienced during nominal system operation.

[c] Optimization parameter.

[d] Modeling based on experimental test data for 0.3 mg Pt/cm^2 total Pt loading. Model extrapolates performance for higher Pt loadings.

[e] $Q/\Delta T$ is a measure of radiator size and is defined as [Stack Gross Power x (1.25 V – Cell Voltage at Rated Power) / (Cell Voltage at Rated Power)] / [Stack Coolant Exit Temperature (°C) - ambient temperature (°C)].

[f] See Figure 2 for additional system cost, status, and target information.

HDV fuel cell systems, originally based on upscaled LDV components, are trending toward HD-specific designs. Stakeholder feedback indicates manufacturers are moving toward larger size cells (currently in the range of 400–600 cm^2 and in the future up to 700–800 cm^2/cell). To limit the number of cells per stack ($\leq$500 cells/stack for structural reasons), keep the active area per cell a reasonable value (considering the amount of membrane area per stack), and enable flexibility in operation, SA chose to have 2 stacks[16] electrically connected in series. Stacks are arranged with gas and coolant connections manifolded in parallel and contain stack shut-off valves to enable stack isolation, as seen in the system diagram in Figure 1. The air system includes a centrifugal air compressor with expander (without motor air-bleed recycle), an air precooler, and membrane humidifiers (one for each stack for 2024). The hydrogen loop contains a combination of hydrogen blower (for recirculation) and injector (for flow control) to achieve superior control compared to an injector/ejector design.

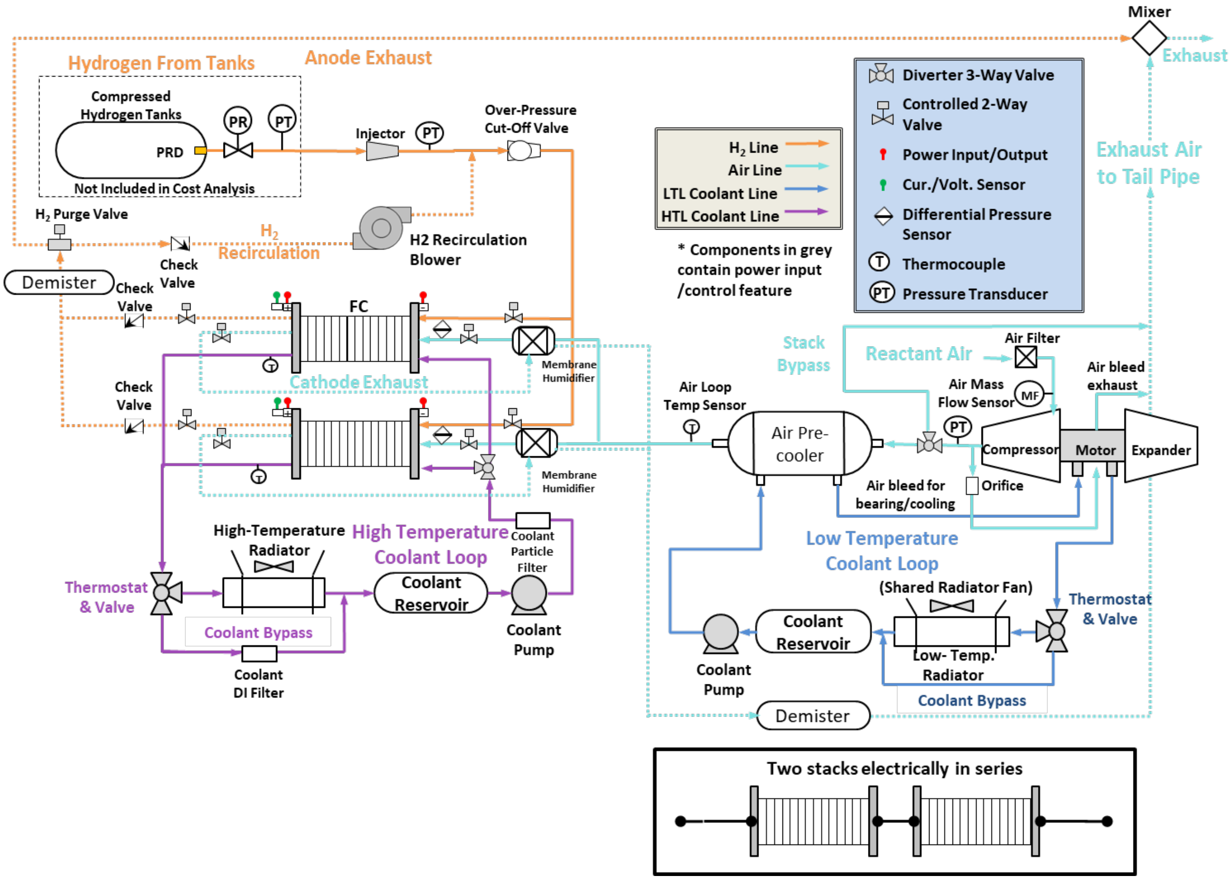

Figure 1. 2024 Class 8 long-haul truck fuel cell system diagram[17]

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[16] In 2022, SA received feedback from multiple companies that the number of stacks should be limited to 2 stacks per HDV system.

[17] The modeled fuel cell system does not currently include a DC/DC converter to convert the variable stack voltage to a near constant battery bus-bar voltage. Although power electronics can impact the truck powertrain cost, this analysis focuses only on the FC system.

Cost Results:

The cost of the HD fuel cell system described and depicted above in Figure 1 are modeled at a rate of 50,000 systems per year to provide the current 2024 cost status. The interim target in 2025 is also at 50,000 systems per year while the 2030 and ultimate targets are presented at an increased manufacturing volume of 100,000 systems per year. The 2023 status[14], current 2024 status[15], and interim target in 2025, as well as the future 2030 and ultimate targets are presented in Figure 2. The 2024 status of $155/kW at 50,000 systems per year is 10% less than the 2023 status of $173/kW at the same production rate. Notably, many medium-duty (MD) and HD fuel cell stack developers are producing modular stack systems that would allow multiple vehicular applications to share a common platform design (e.g., stack and BOP) leading to greater economies of manufacturing scale. 2023 MD and HD diesel truck sales in the U.S. are 240,525 trucks/year and 266,752 trucks/year, respectively.[18] Consequently, future high-volume production from a single fuel cell manufacturer of 50,000 to 100,000 per year is reasonable, particularly if a high degree of stack commonality is achieved that would additionally benefit other applications. The 2025 interim, 2030, and ultimate targets are $140/kW$_{net}$, $80/kW$_{net}$, and $60/kW$_{net}$, respectively. Both anticipated technology improvements and increased manufacturing volumes are needed to reach future cost targets.

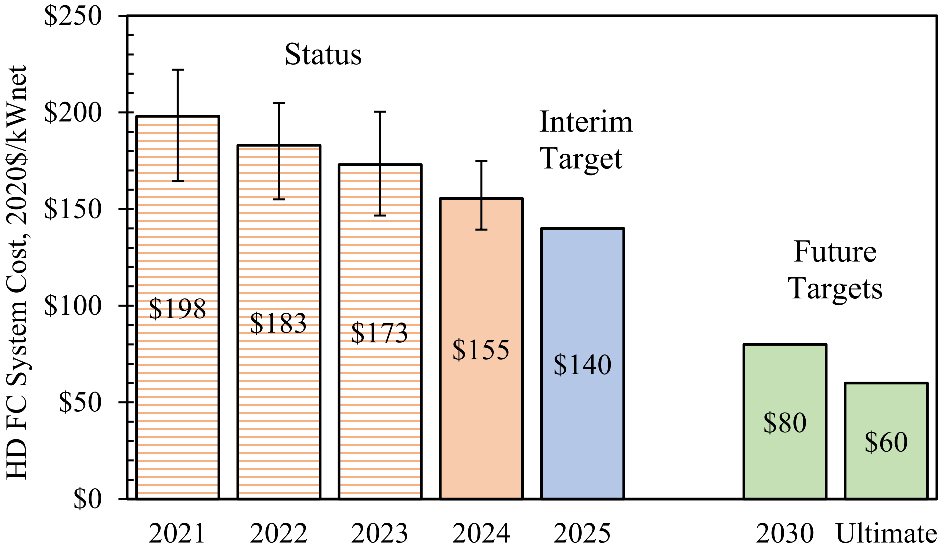

Figure 2. Modeled HD fuel cell system cost status (2021, 2022, 2023, and 2024) compared to the interim target (2025) for a manufacturing volume of 50,000 systems per year. Future (2030, $80/kW) and ultimate ($60/kW) targets at 100,000 systems per year.[19]

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[18] 2023 U.S. truck sales from American Truck Dealers (ATD) Truck Beat. https://www.nada.org/atd/atd-insider/atd-truck-beat-2023-commercial-truck-sales-reach-half-million-first-time-2019

[19] While the cost results, particularly the $/kW results, are presented to three significant figures, this should not be construed to indicate that level of accuracy in all cases. Rather, results are presented to a high level of monetary discretization to allow discernment of the direction and approximate magnitude of cost changes. Those minor impacts might otherwise be lost to the reader due to rounding and rigid adherence to rules for significant digits or might be misconstrued as an error or as having no impact.

To assess the impact of manufacturing volumes on overall system costs, the system cost is projected at manufacturing rates from 1,000 to 100,000 per year, as shown in Figure 3. The projected cost of the HD truck fuel cell system at a production rate of 50,000 units/year is \$155/kW$_{net}$ using 2024 technology. Error/Uncertainty bars are added to the data points based on Monte Carlo analysis and represent the range of cost results containing the true cost with 90% confidence.

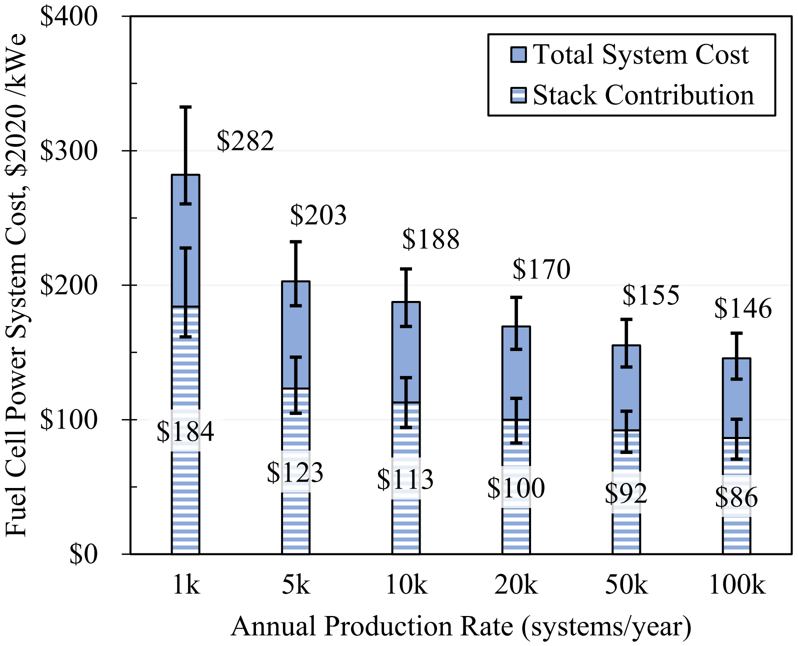

Figure 3. Modeled cost of a 275-kW$_{net}$ PEM fuel cell system in 2020\$ based on projection to high-volume manufacturing (100,000 units per year) for 2024 technology years. Error bars represent the 90% confidence interval from a stochastic uncertainty analysis and reflect manufacturing uncertainty in the modeled system.

Key Cost Assumptions

1. **Cost Definition:**
Fuel cell system cost to a truck OEM with added markup for Powertrain System Integrator.
2. **Scope of Cost:**
Includes Fuel Cell Module Capital Expenditures and Maintenance costs over 25,000 operating hours. Includes radiator/fans. Excludes DC/DC converter, battery, and H_2 storage subsystem.
3. **\$/kW$_{net}$ based on system EOL power level (275 kW$_{net}$)**
4. **Cost reported in 2020\$**
5. **Pt Price \$1,500/tr oz**

The system cost may be separated into component costs as shown in Figure 4 and Figure 5. Notably, the stack cost represents the majority, circa 60%, of the total 2024 HD fuel cell system cost. The large active area and high Pt loading (0.35 mg Pt/cm^2 total) result in the catalyst cost being more than half the stack cost at high production volume. The BOP cost is driven by the air loop, BOP replacement cost[20], and high temperature coolant loop; combined, they make up almost 70% of the BOP cost as seen in the pie chart in Figure 5. There are economies of scale for the absolute cost of the BOP components, however, there is little variation in the cost percentage for each BOP component between low (1,000 systems per year) and high (100,000 systems per year) production volumes. Unlike the fuel cell stack, the BOP components are not oversized to meet the 25,000-hour vehicle lifetime. Instead, the HDV components follow the strategy used in conventional diesel trucks, wherein many BOP components will be designed to meet the lifetime of the vehicle. However, other BOP components, which may not be specifically designed for the HDV application, are based on LDV BOP components and replaced several times during the HDV lifetime. The supplier base is expanding offerings of more robust and larger BOP

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[20] BOP replacements over the 25,000 hours vehicle service life include air filters (nine replacements), the H_2 recirculation pump (single replacement), air humidifier (single replacement), and coolant ion exchange filters (nine replacements). Additionally, an installation labor cost is included in the BOP replacements cost and is estimated based on the labor hours to replace components and a labor rate of \$57/hr.

components specifically for HDV fuel cell systems. The fuel-cell-specific BOP components that do not currently achieve 25,000 hour durability are tracked through BOP component replacement costs (included in the estimates) to measure progress in both durability and performance of HDV BOP components.

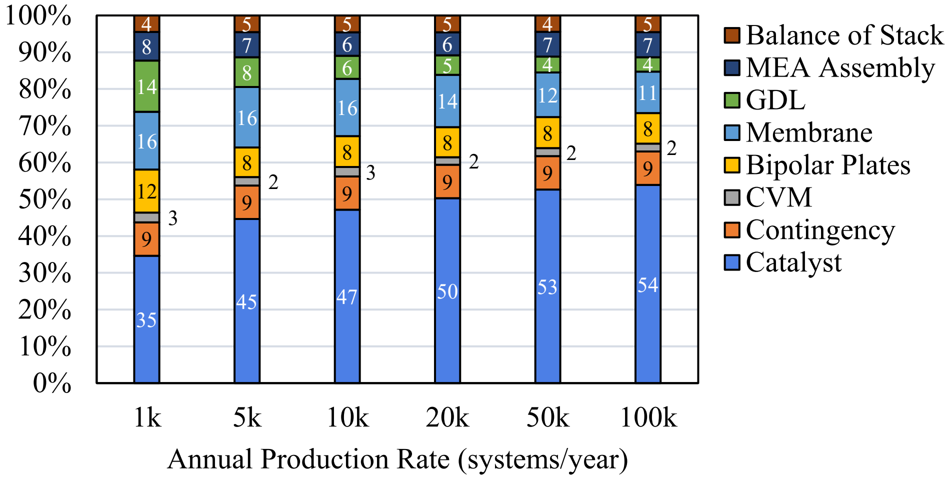

Figure 4. 2024 HDV stack component cost breakdown at all modeled production volumes (CVM: cell voltage monitor). Values on bars are percentages.

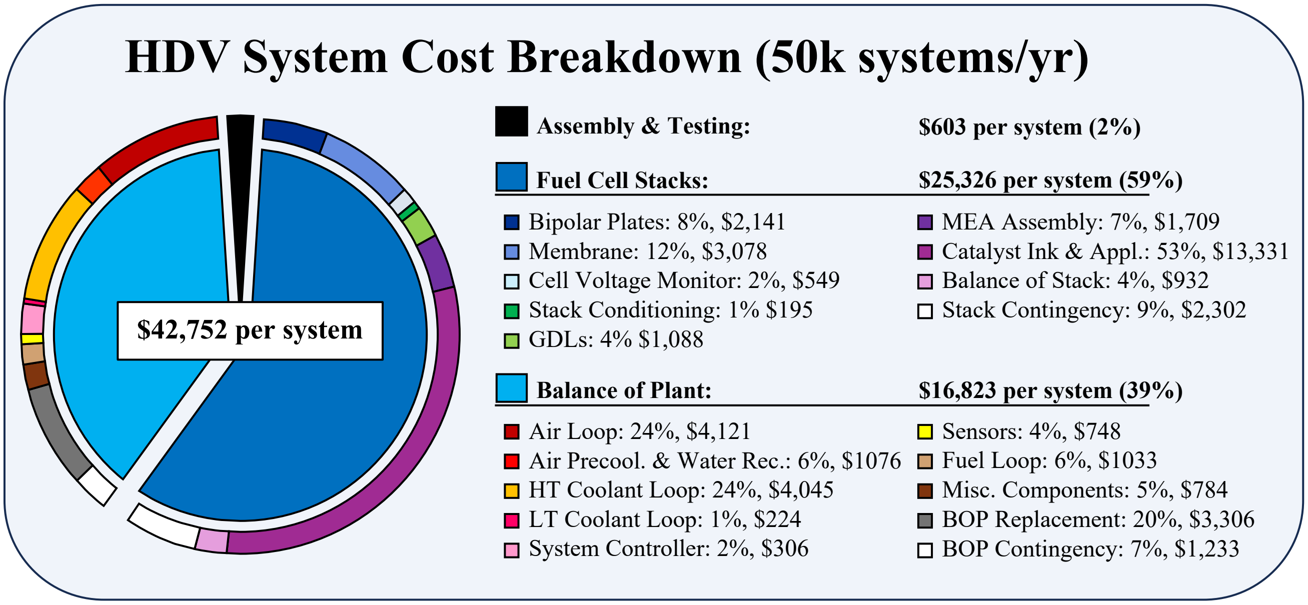

Figure 5. 2024 Cost breakdown for system components at 50,000 systems per year. Outer-ring percentages are based on the respective Balance of Plant or Fuel Cell Stacks category cost.

Sensitivity Analysis:

A single variable sensitivity analysis at 50,000 systems per year is shown in Figure 6 and Figure 7 and indicates the system cost impact from a change in a single variable. The uncertainty parameters are summarized in Table 2.[21] An additional parameter is included in the 2024 sensitivity analysis, the BOP replacement cost (percentage of total BOP cost). The multi-variable Monte Carlo sensitivity analysis estimates uncertainty in the total system cost due to multiple variables changing simultaneously. From the Monte Carlo results, the 2024 system cost at 50,000 units per year is projected to be between \$139/kW and \$175/kW (Figure 7) with 90% confidence. Uncertainty in power density reflects industry feedback on possible performance. The EOL power density influences the amount of oversizing of the active area, however, there is a separate active area oversizing uncertainty parameter incorporated within the Monte Carlo analysis to reflect uncertainty in the ECSA loss experienced over the stack lifetime.[22]

Fuel Cell System Improvement Opportunities:

With the increased focus on HDV fuel cell systems, rapid learning is occurring. Multiple pathways are being pursued to improve fuel cell stack and BOP components, along with alternative system architecture designs. Conversations with industry continually reveal new engineering techniques to overcome both durability and performance issues.

For the fuel cell stack, improvement opportunities include 1) increasing the EOL power density via advanced membranes, improved catalysts, reduced membrane thickness, 2) decreasing cathode catalyst loading, 3) manufacturing improvements, and 4) increasing stack operating temperature. Fuel cell stack advancements will result in smaller cells and fewer cells per stack. BOP cost reductions can be achieved by reducing the number of BOP components, such as using only a single cathode humidifier, and reducing and/or eliminating BOP replacements.

As commercial adoption accelerates and the cumulative deployment of HDV fuel cell systems grows in the coming years, significant component and system-level improvement opportunities are expected. Continued refinements and incorporation of improvements, including those listed above, are likely to alter the ultimate configuration of HDV systems. Future cost records will be updated to both track progress and reflect changes to the modeled HDV systems.

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[21] The range in parameter values for the single variable sensitivity analysis are the same as the multi-variable sensitivity analysis parameter values. The air loop cost in the tornado chart includes the combined variations in the air compressor cost, compressor-expander-motor (CEM) efficiencies, and balance of air compressor cost variation.

[22] Oversizing percentage values are calculated: (active area to reach EOL conditions) / (active area for a system with 0% ECSA loss) - 1.

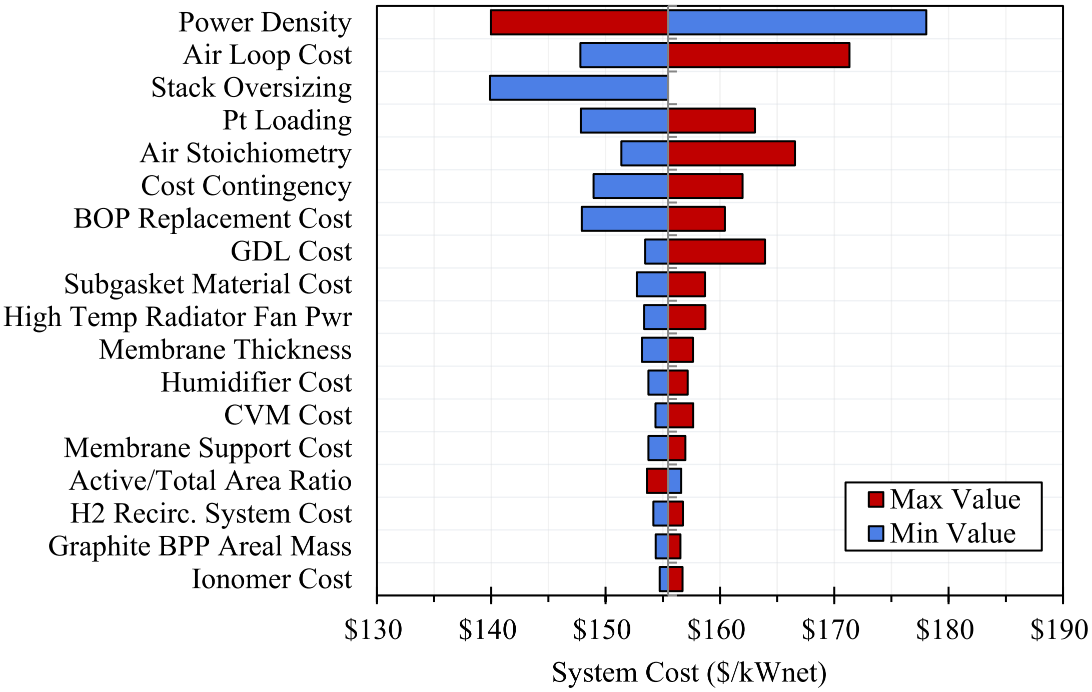

Figure 6. Tornado chart of single variable sensitivity analysis of HDV system cost at 50,000 systems per year.[23]

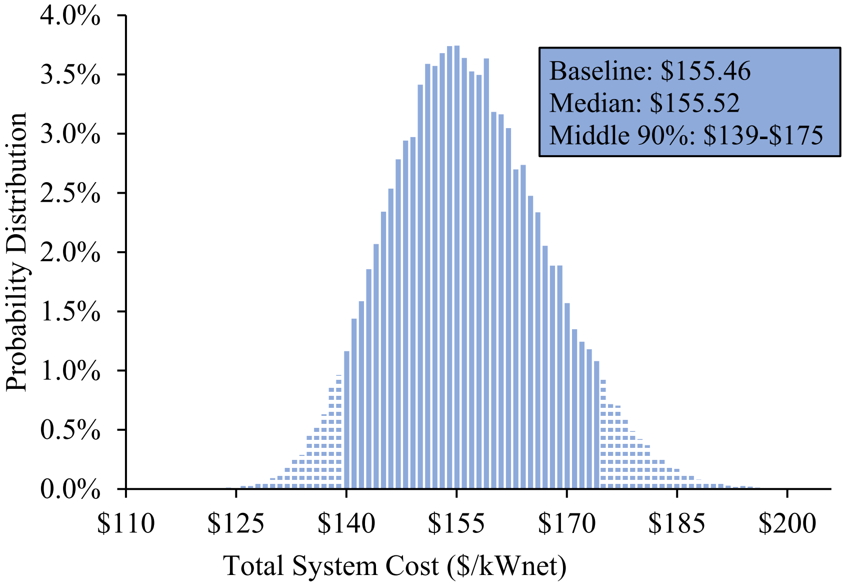

Figure 7. Monte Carlo analysis of system cost probability at 50,000 systems per year.

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[23] Acronyms: gas diffusion layer (GDL), cell voltage monitor (CVM), expanded polytetrafluoroethylene (ePTFE), bipolar plate (BPP)

Table 2. 2024 HDV Technology Tornado and Monte Carlo Analysis at 50,000 systems per year

	Parameter [a]	Units	Baseline [b] | Min-Max Value		Bounds Rationale (min | max)
	Power Density	mW/cm^2	642	500 - 802	500 mW/cm^2 | +25% based on industry feedback on possible range
Air Loop	Compressor Efficiency	%	72%	65% - 75%	ANL's assumptions for range in compressor/expander/motor/controller efficiencies
	Expander Efficiency	%	75%	71% - 80%	
	Motor/Controller Efficiency	%	84%	80% - 90%	
	Air Compressor (CEM) Cost	$/system	$3,009	$2,708 - $3,611	90% | 120% of calculated cost
	Balance of Air Compressor Cost	$/system	$839	$562 - $1,426	66% | 170% of calculated cost (170% = 150% base value with added 20% more for four $50 components possibly included: gas-capture filter, resonator, and shut-off valve)
	Stack Oversizing	%	67%	33% - 67%	50% based on feedback of limit on active area of stack | No change from baseline value
	Total Pt Loading	mgPt/cm^2	0.35	0.30 - 0.40	0.3 mg Pt/cm^2 at low end based on amount needed for durability
	Air Stoichiometry	-	1.5	1.3 - 2	HD fuel cell system integrators recommendation | Reasonable system operating condition
	Cost Contingency	%	10%	5% - 15%	-50% on the baseline value | +50% on the baseline value
	BOP Replacement Cost	%	27%	10% - 38%	NEW: Half the replacements, remove H_2 recirc pump and humidifier | 12 replacements for air filter and coolant ion exchange filter, 2 replacements of humidifier
	GDL Cost	$/m^2 of GDL	$8.48	$4.58 - $24.99	Lower bound of reported GDL costs ($3/m^2) | OEM suggested >$16/m^2
	HTL Radiator Fan Power	kW	25.8	23 - 30	EMP fan power for Class 8 HD fuel cell truck | 30 kW
	Sub-gasket Material Cost	$/m^2 of PEN	$5.13	$2.15 - $8.61	$2/m^2 if use similar PET cost | $8/m^2 if up to 4x the cost of PET
	Membrane Thickness	µm	15	10 - 20	Range based on feedback from HD fuel cell system integrators and OEMs
	Hydrogen Recirculation System Cost	$/system	$1,033	$775 - $1,291	75% | 125% of calculated cost
	Humidifier Cost	$/system	$517	$259 - $776	-50% on the computed baseline value | +50% on the computed baseline value
	CVM Cost	$/kW	$1.63	$0.81 - $3.26	+100% on the computed likeliest value | -50% on the computed likeliest value
	Membrane Support Cost	$/m^2 of ePTFE	$9.68	$4.84 - $14.00	Range of industry quotes
	Active to Total Area Ratio	-	0.625	0.55 - 0.8	Based on discussions with vendors | Value used in previous year studies
	Graphite BPP Areal Mass [c]	kg/m^2	0.5	0.4 - 0.6	+/- 0.1 kg/m^2
	Ionomer Cost [d]	$/kg	$658	$592 - $770	-10% | Extrapolation of quoted ionomer cost of $770/kg at 95 tons/year or 50,000 HDV systems/year

[a] The Monte Carlo analysis treats each parameter as an independent variable with respect to power density. Thus, changes to operating conditions (such as catalyst loading, pressure, etc.) do not alter the power density for purposes of the Monte Carlo analysis.

[b] For all parameters, the "Baseline Value" is set to the 2024 cost analysis baseline model value for that parameter. Min and max represent the lower and upper bound for the single variable sensitivity analysis and the lower and upper bound for the triangular distribution used in Monte Carlo analysis.

[c] Although graphite bipolar plates are used in the baseline in this 2024 analysis, there are plans to include the cost of metallic bipolar plates in future sensitivity analysis.

[d] Ionomer cost here is represented by both the ionomer in the catalyst ink and the ionomer in the membrane. The range in cost affects both the catalyst ink cost and the membrane material cost.