

Impact of Fuel Cell and Storage System Improvement on Energy Consumption and Cost

Namdoo Kim, Ayman Moawad, Ram Vijayagopal, Aymeric Rousseau
Argonne National Laboratory

Introduction

Quantify the impact of fuel cell system improvements on energy consumption and economic viability of fuel cell powered vehicles

- DOE baseline and scenario analysis show that by 2025, Fuel Cell Electric Vehicles (FCEVs) may have similar or lower cost of ownership as the fossil fuel powered vehicles.
- Many technologies that help FCEVs are expected to evolve during this time.
 - e.g. light weighting, improved aerodynamics
- Do FCEVs depend on ‘other’ technologies to be viable?
 - If fuel cell technology development meet their targets, and other technologies stagnate, can FCEVs be economically feasible
- Analysis will reveal :
 - Impact of fuel cell system improvement on cost of driving FCEVs
 - Impact of H₂ storage improvement on cost of driving FCEVs
 - Are the current fuel cell & storage technology targets sufficient to make FCEVs viable even with current vehicle technology

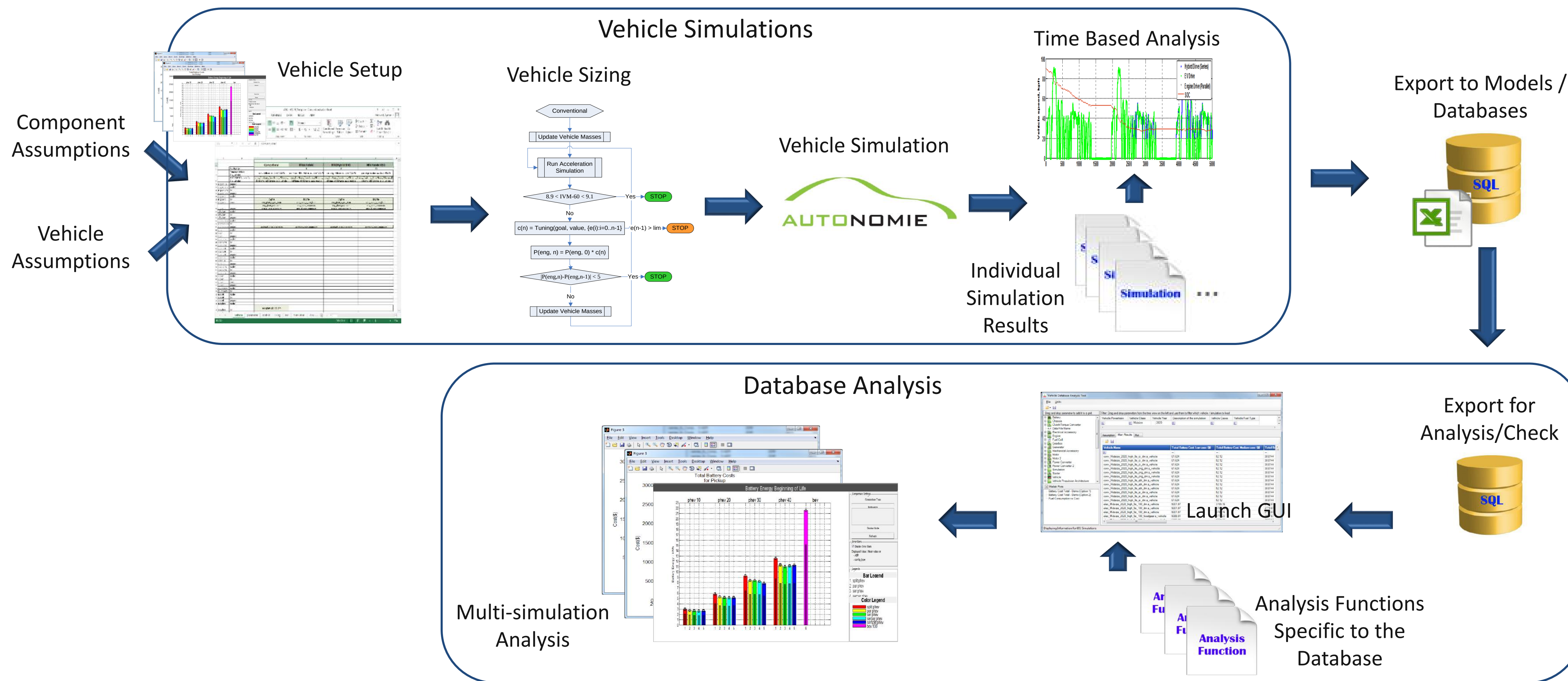
Objective

The objective is to evaluate the impact of fuel cells and storage technology, on cost & energy consumption of FCEVs.

- Size the vehicles to meet similar vehicle technical specifications (i.e. performance, range...) with following assumptions.
- This study considers 3 scenarios:
 - Fuel Cell (FC) System Impact : Fuel cell system improves over time
 - Hydrogen Storage (H2) System Impact : Hydrogen Storage system improves over time
 - Combined (H2 + FC) Impact : Both Fuel cell & Hydrogen systems improve over time
- All other vehicle technologies remain as they are in 2015
- Estimations using EPA's Combined 2 cycle procedure (UDDS & HWFET)
- Compare 'Energy Consumption', 'Vehicle Cost' & 'LCOD'
- Scope of the study is restricted to midsize light-duty vehicles
 - Contributions from 'non fuel-cell' technologies is not considered in this study.

Process for Running and Analyzing Large-scale Simulations

- To evaluate the fuel efficiency benefits of advanced FC and hydrogen tank systems, each vehicle is designed with individual component assumptions to meet the same vehicle technical specifications.

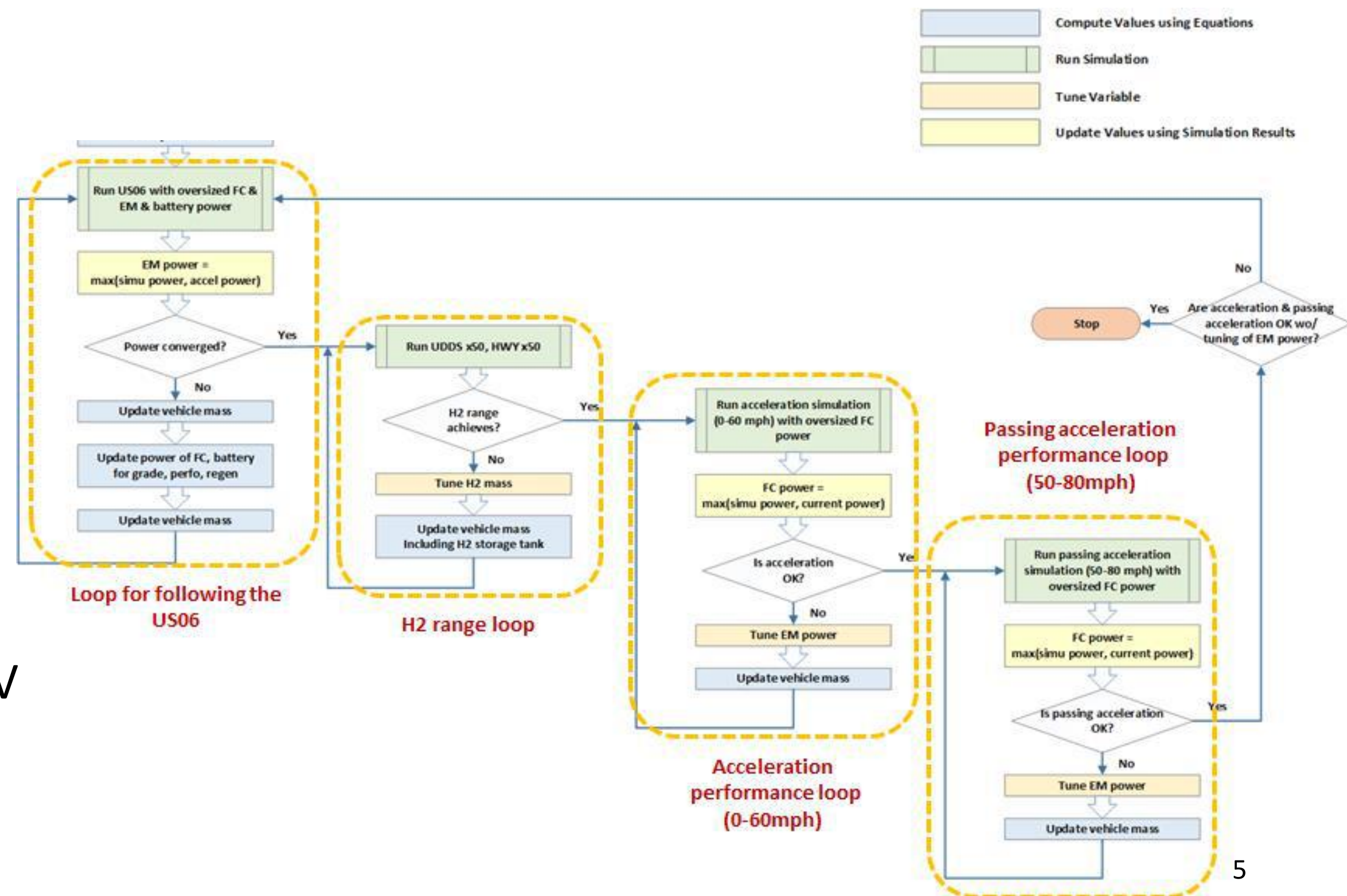


Approach

- Series configuration for FC HEVs in Autonomie



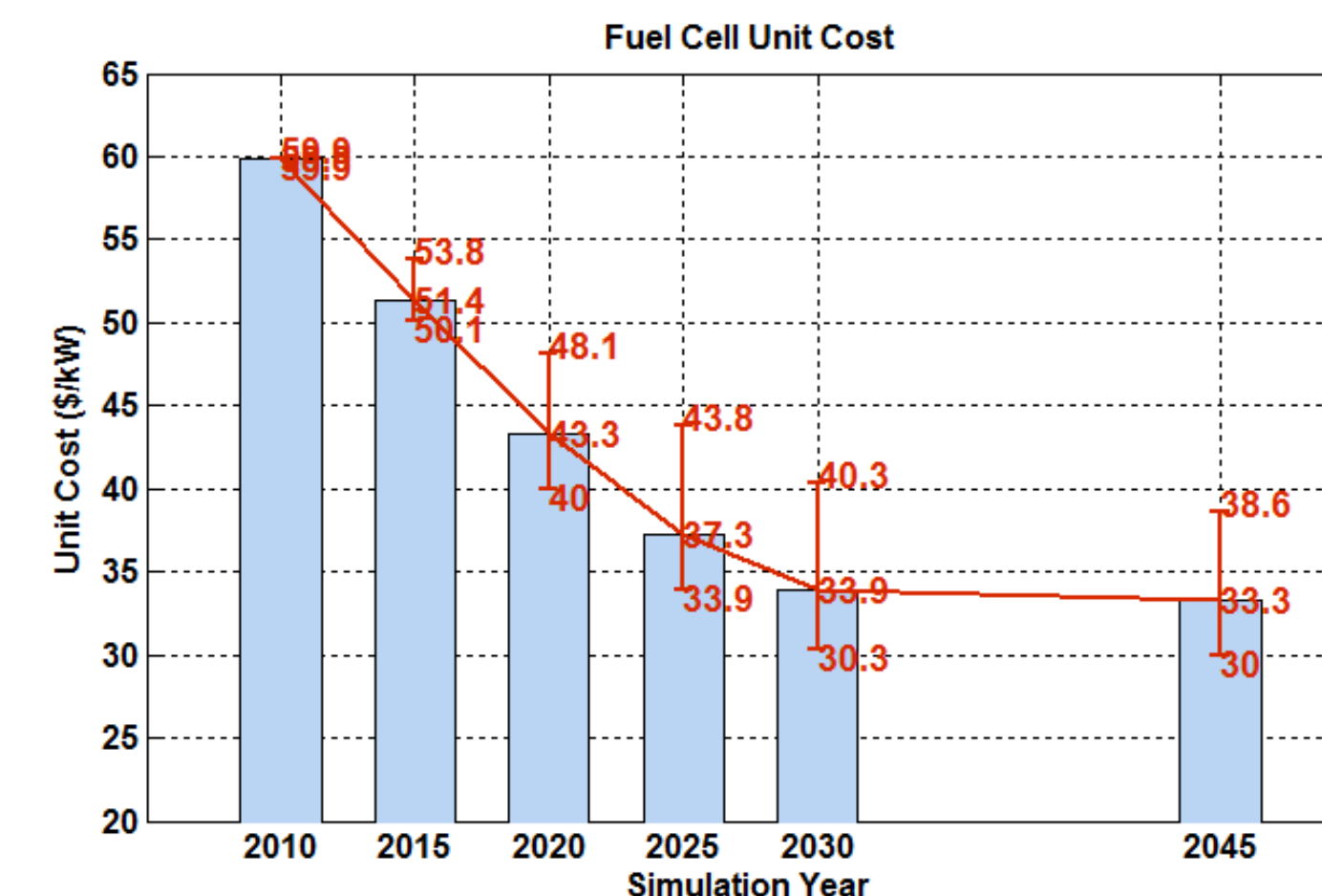
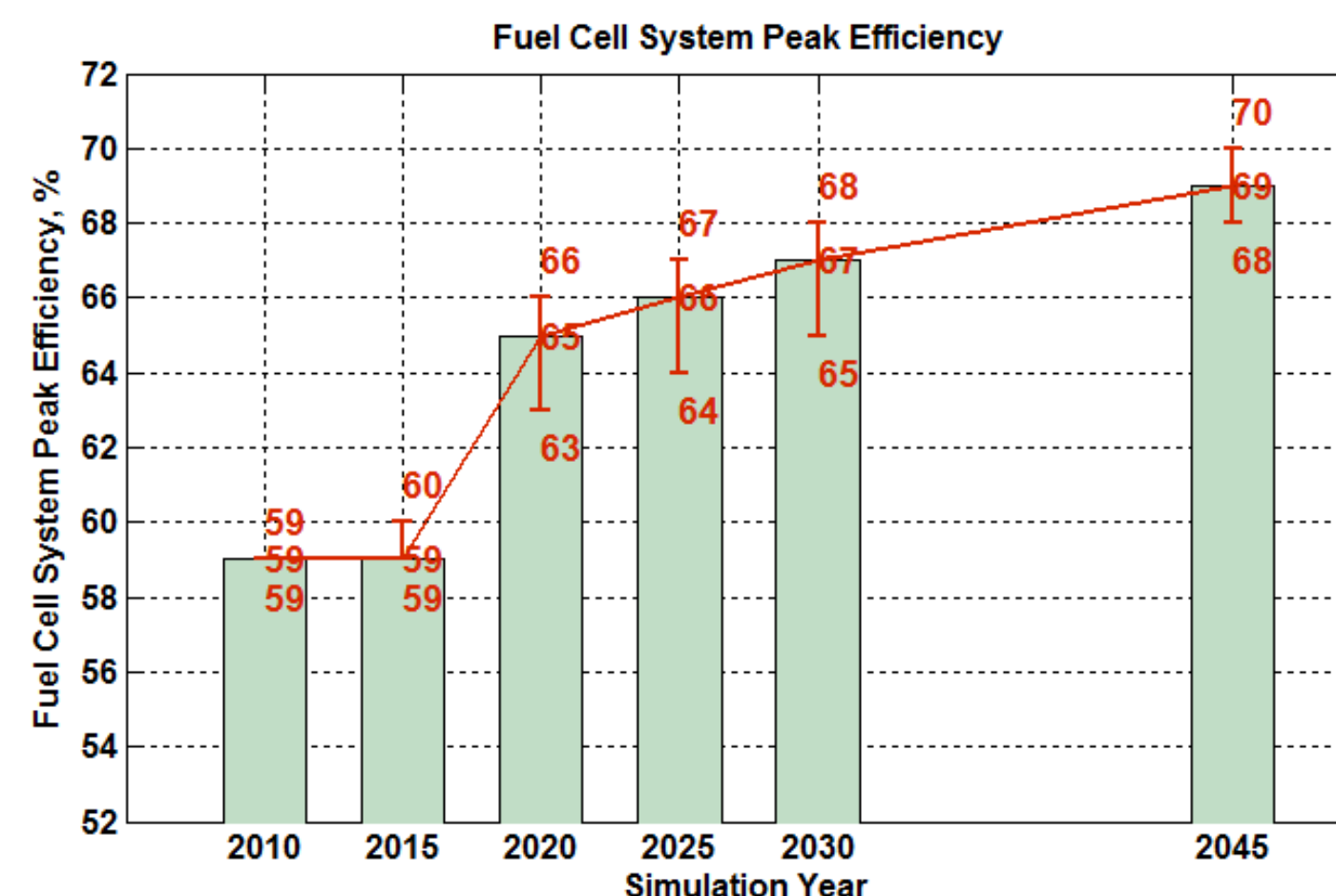
- FC HEV powertrain sizing algorithm
 - FC power: sized to meet 70% of peak power required to meet Vehicle Technical Specifications (acceleration performance, grade-ability...).
 - Battery power: sized to recuperate 100% energy on UDDS.
 - Electric machine power: sized to follow the US06 in EV mode at low SOC or to meet the requirement of acceleration performance.



Fuel Cell System Assumptions – Efficiency and Cost

Parameter	Units	2010	2015			2020			2025			2030			2045		
			low	med	high	low	med	high	low	med	high	low	med	high	low	med	high
Peak Fuel Cell System Efficiency	%	59	59	59	60	63	65	66	64	66	67	65	67	68	68	69	70
Platinum Price	\$/Troy OZ	\$1,100	\$1,500			\$1,500			\$1,500			\$1,500			\$1,500		

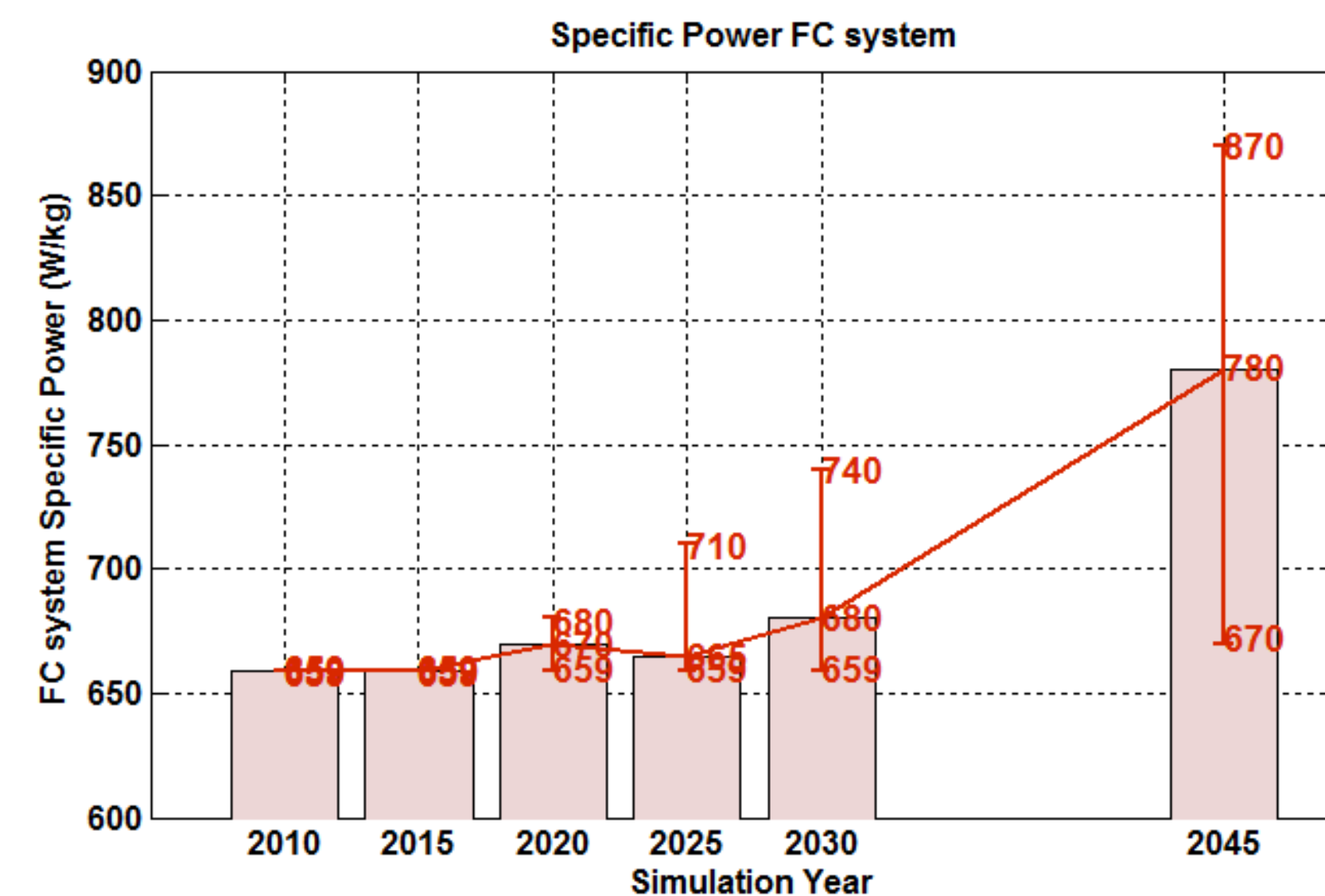
- Fuel.Cell.Cost = $(x \cdot 1246.5 \cdot (\text{Stack.UnitsPerYr})^{0.2583 + (\text{Pt.Price} \cdot y)}) \cdot \text{Fuel.Cell.kW} \cdot (\text{Fuel.Cell.kW} / \text{Base.80kW})^z$
 - (x,y,z): Coefficients
 - Stack.UnitsPerYr = 500,000
 - Pt.Price: Platinum Price
 - Fuel.Cell.kW: Fuel Cell Power
- Costs are assumed for high production volumes.



Fuel Cell System Assumptions – Specific Power

Parameter	Units	2010	2015			2020			2025			2030			2045		
			low	med	high	low	med	high	low	med	high	low	med	high	low	med	high
Specific Power FC System	W/kg	659	659	659	659	659	670	680	659	665	710	659	680	740	670	760	870
Power Density	W/L	640	640	640	640	640	720	850	640	730	890	640	740	970	690	880	1150

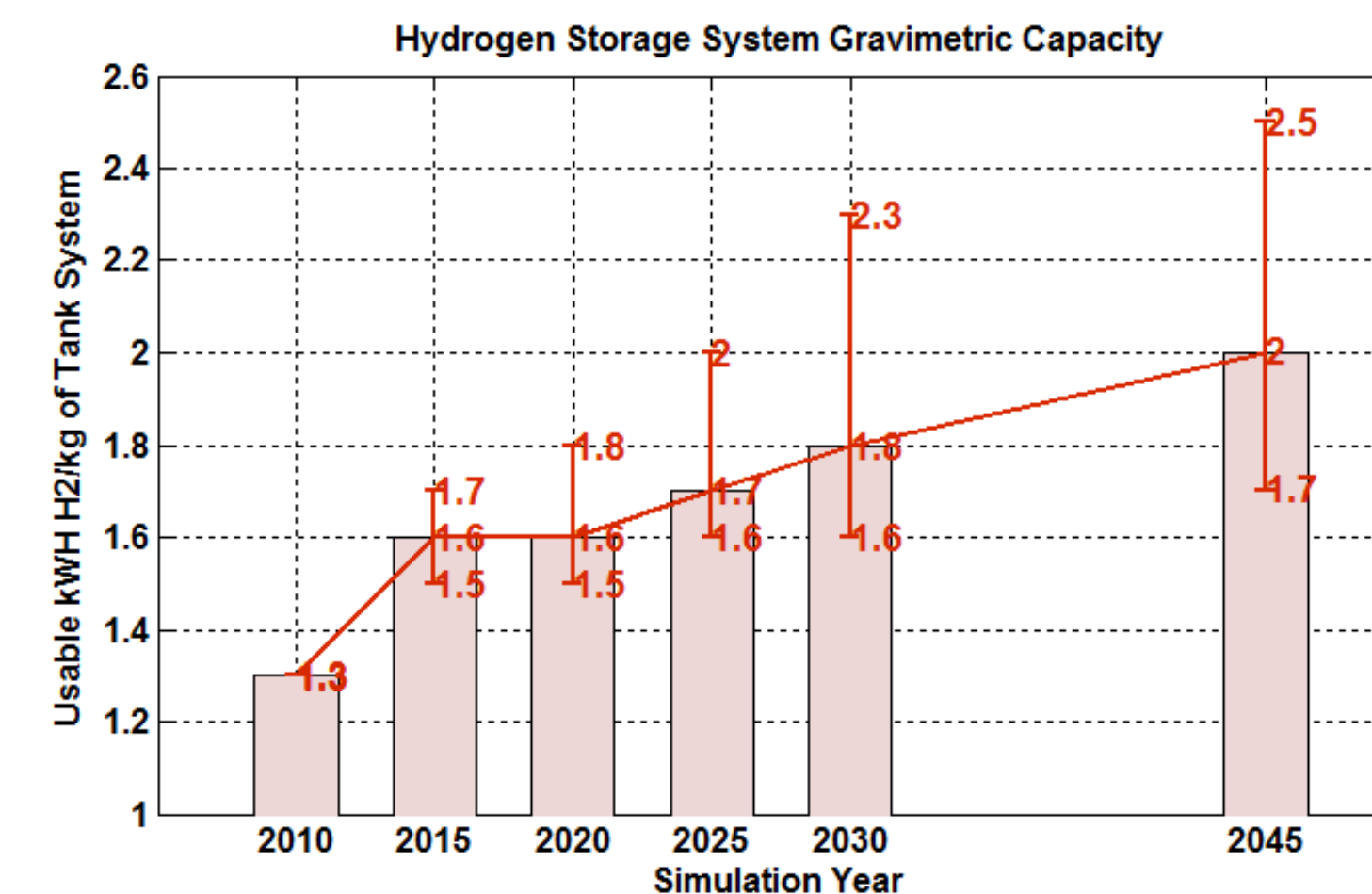
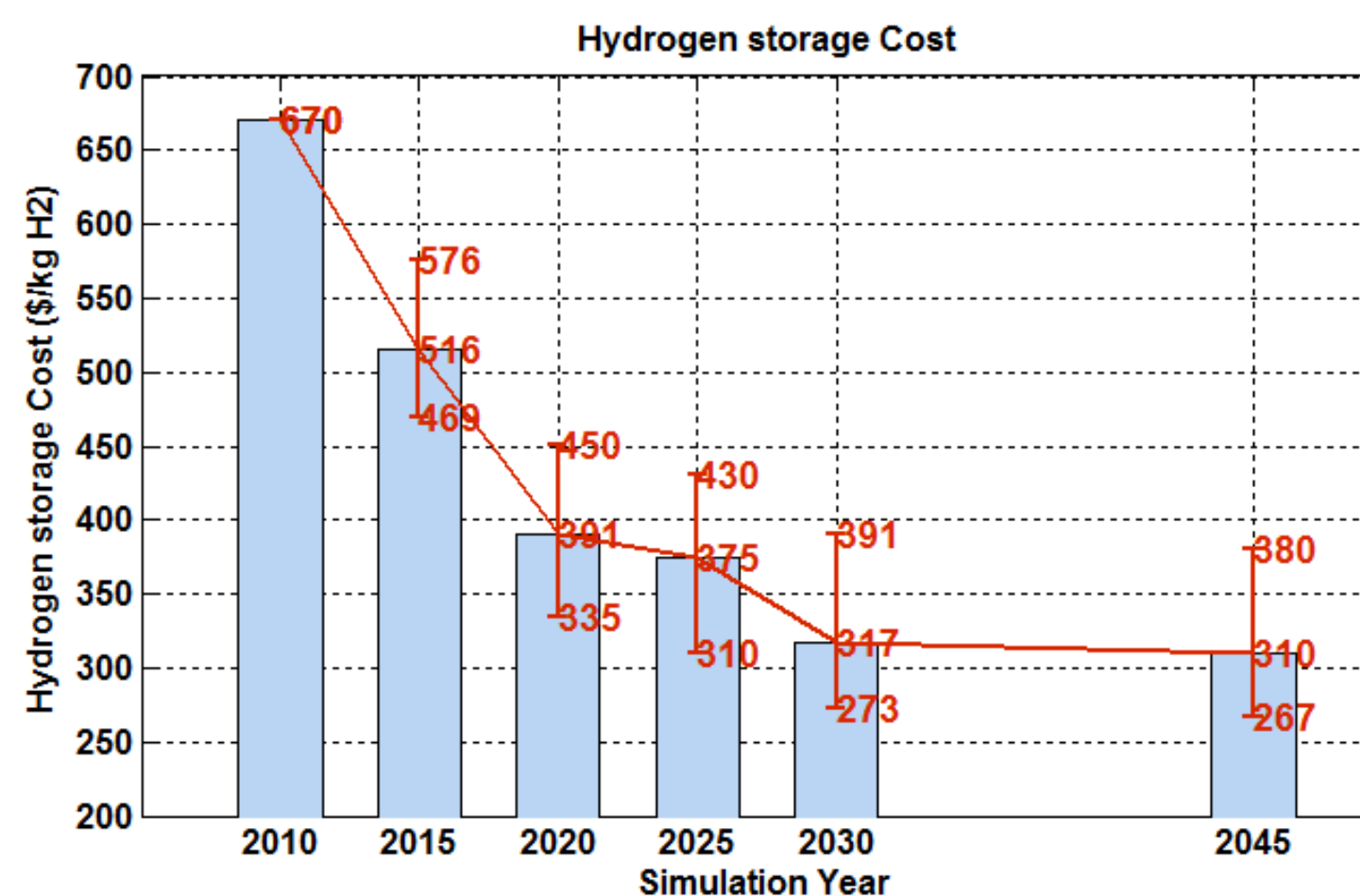
- Fuel.Cell.Weight = Fuel.Cell.kW / Specific Power FC System
- Volume is not considered in this analysis



Hydrogen Storage Assumptions

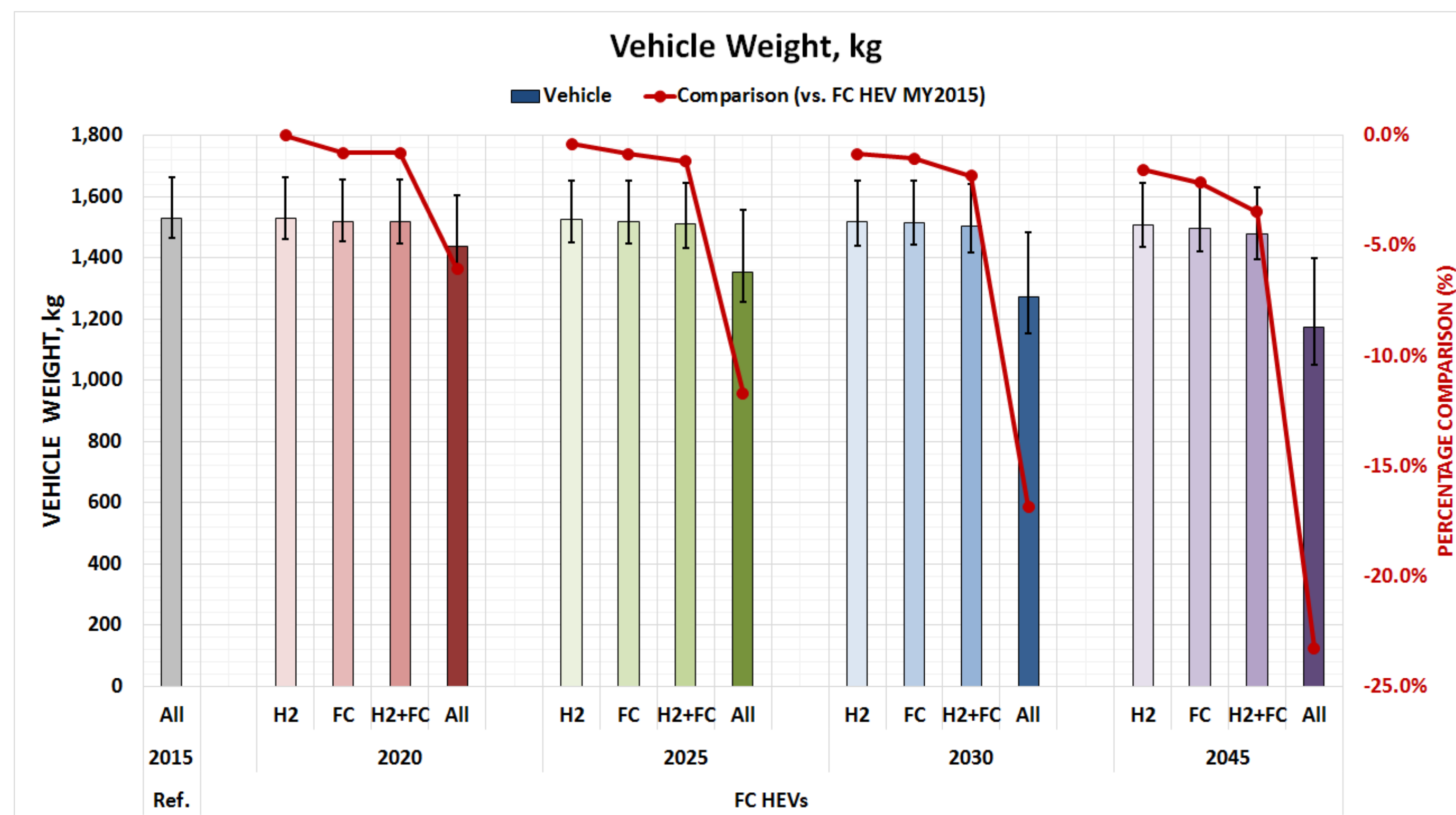
Parameter	Units	2010	2015			2020			2025			2030			2045		
			low	med	high	low	med	high	low	med	high	low	med	high	low	med	high
System Gravimetric Capacity	Useable kWh/kg	1.3	1.5	1.6	1.7	1.5	1.6	1.8	1.6	1.7	2.0	1.6	1.8	2.3	1.7	2	2.5
	Useable kg H2/kg of Tank	0.040	0.045	0.048	0.051	0.045	0.048	0.054	0.048	0.051	0.060	0.048	0.054	0.069	0.051	0.060	0.075
Cost	\$/Useable kg H2	670	576	516	469	450	391	335	430	375	310	391	317	274	380	311	267
Percentage H2 used in Tank	%	95	96	96	96	96	96	96	96	96	97	96	97	97	96	97	97

- $H2.Storage.Cost = Cost.Coefficient * Fuel.Mass$
- $H2.Storage.Mass = Fuel.Mass / Gravimetric.Capacity$



Fuel Cell Vehicles Weight

- Without light weighting and improvement in other component technologies, fuel cell vehicle weight decreases slightly with time.

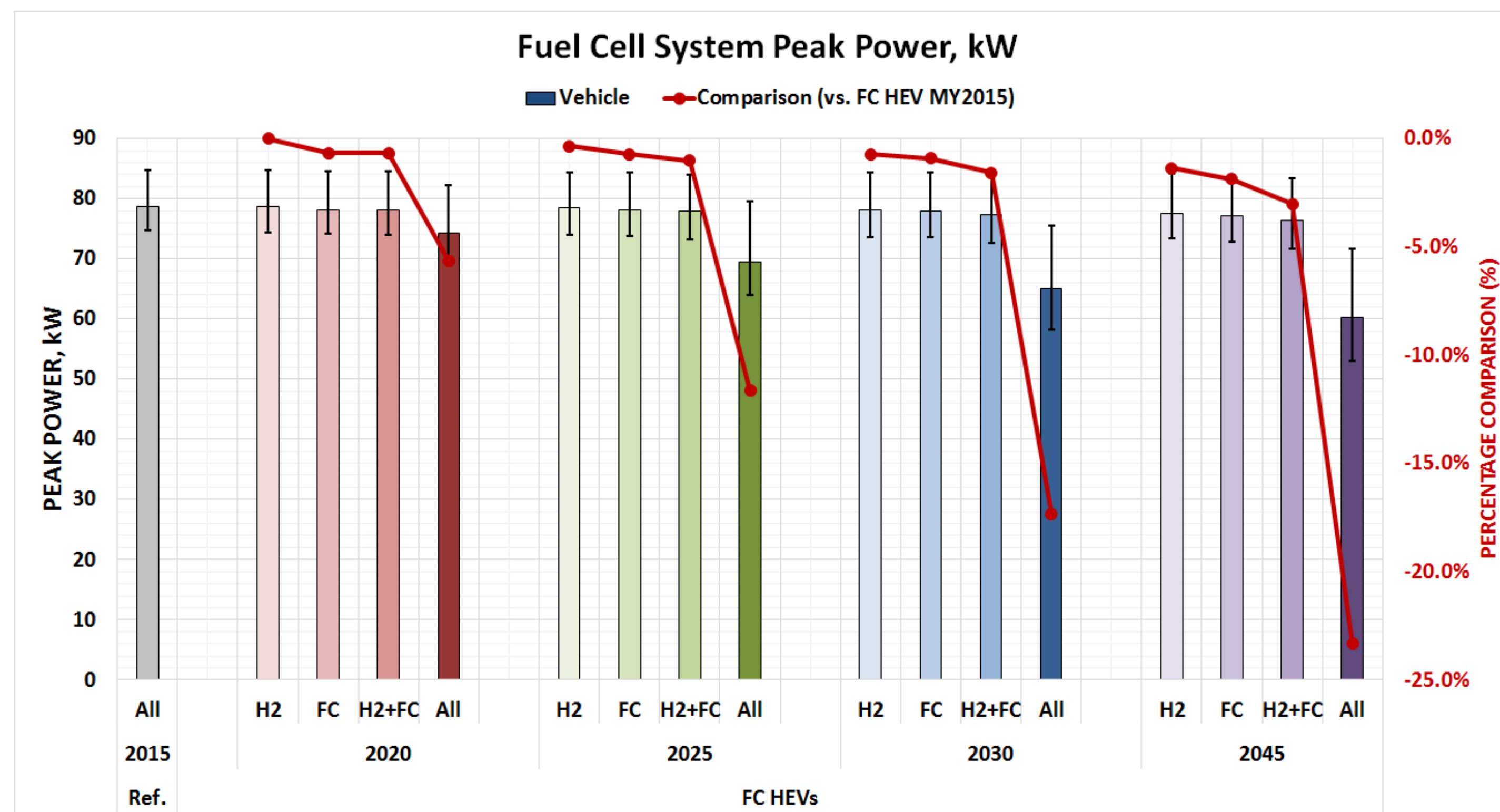


2015			
2020	2025	2030	2045
2020	2025	2030	2045
2020	2025	2030	2045
2020	2025	2030	2045

Ref. : MY2015 Midsize FC HEVs with all technologies from MY2015 year
H2 : MY2015 Midsize FC HEVs with H2 storage technology alone from that Year
FC : MY2015 Midsize FC HEVs with FC system technology alone from that Year
H2 + FC : MY2015 Midsize FC HEVs with H2 storage + FC system technologies alone from that Year
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Fuel Cell System Peak Power

- Due to fuel cell system and hydrogen storage only technology improvements, the fuel cell system powers are expected to decrease by up to -2.5%.

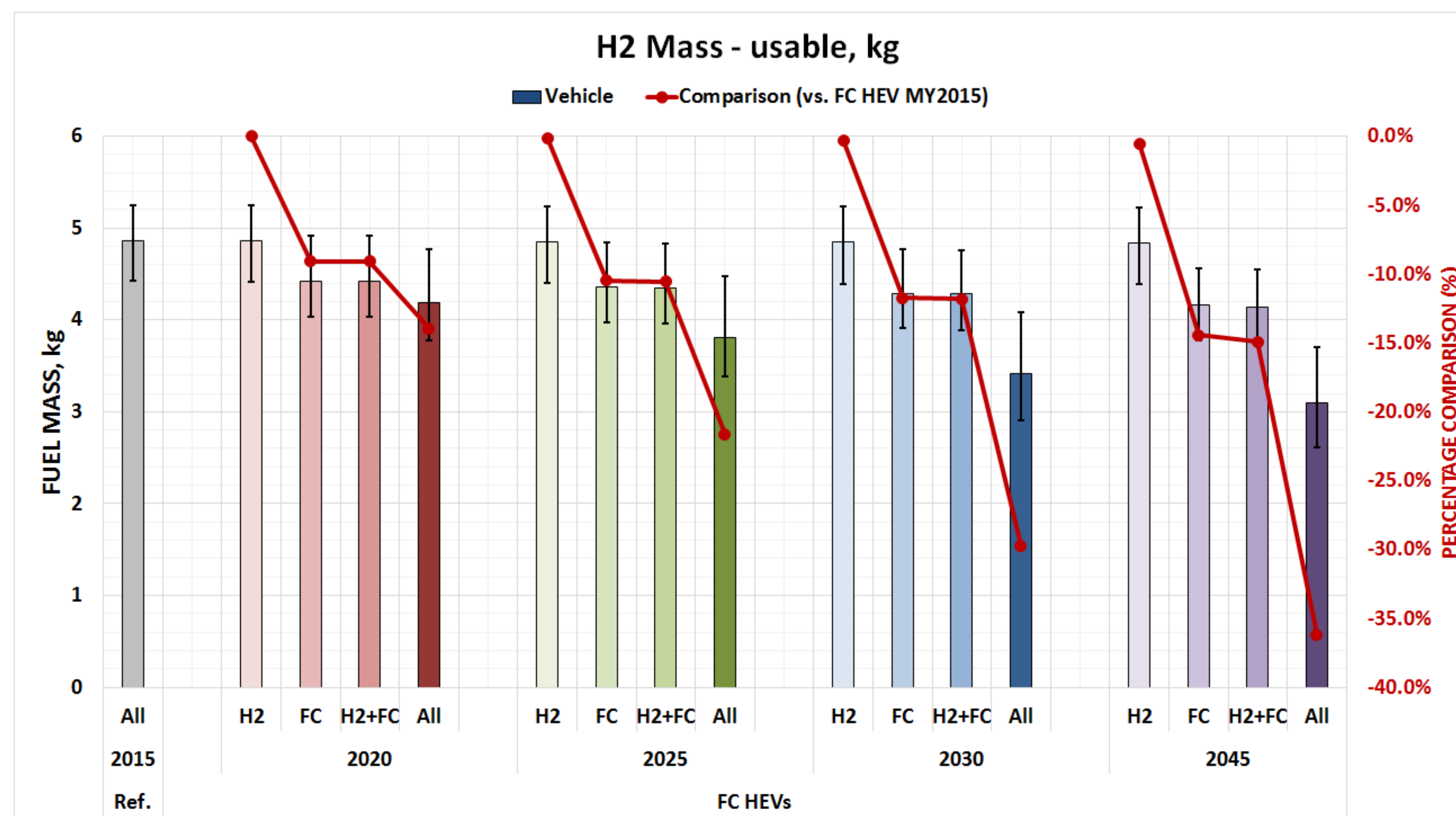


2015			
2020	2025	2030	2045
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Hydrogen Fuel Mass

- The hydrogen fuel mass decrease is mostly due to the fuel cell system improvement. Required on-board hydrogen fuel mass could drop by 15%, due to the fuel cell system technology improvements only.

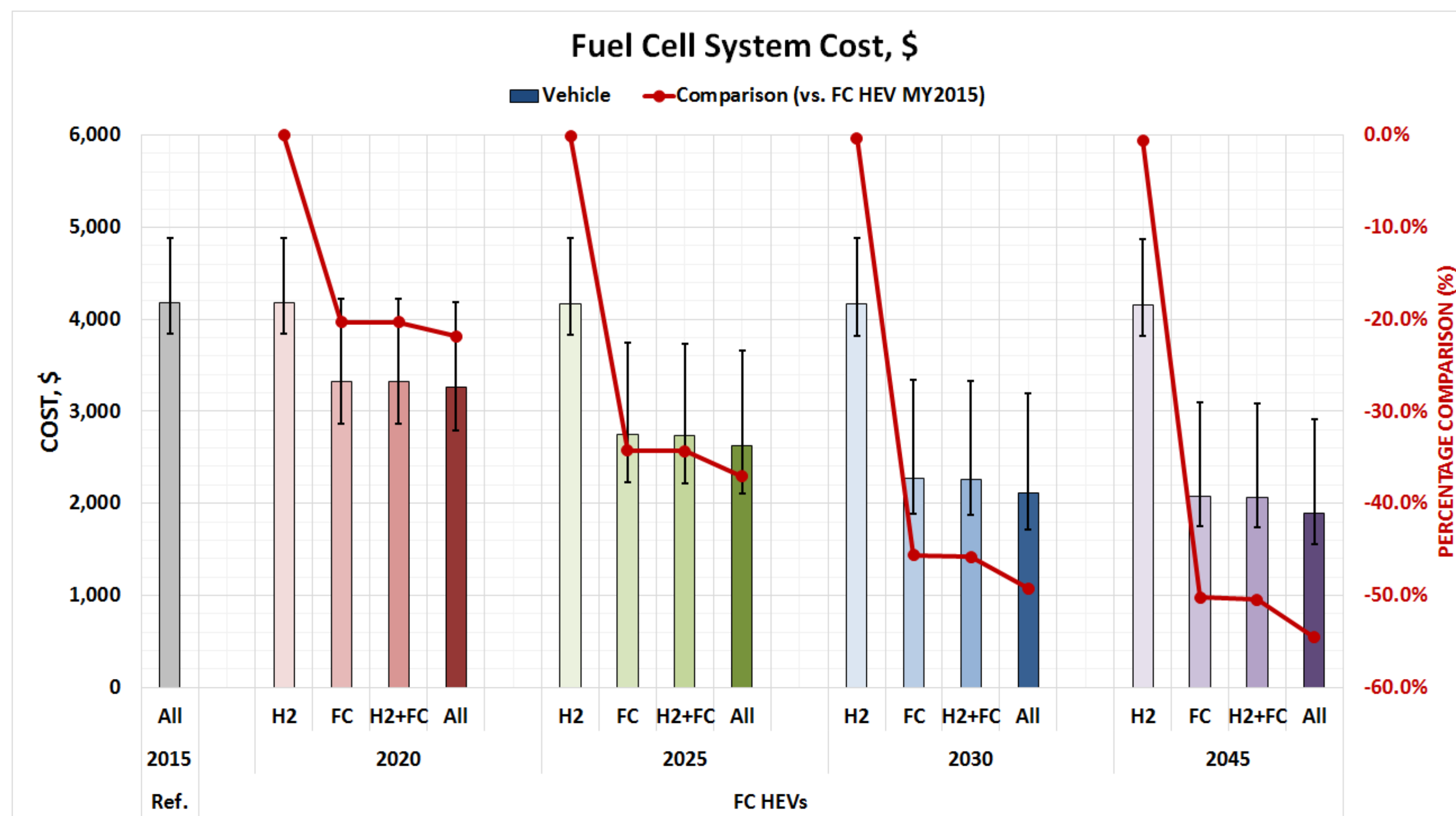


2015			
2020	2025	2030	2045
2020	2025	2030	2045
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Fuel Cell System Cost

- Fuel cell system cost could decrease by 50%, due to the fuel cell system technology improvements only.

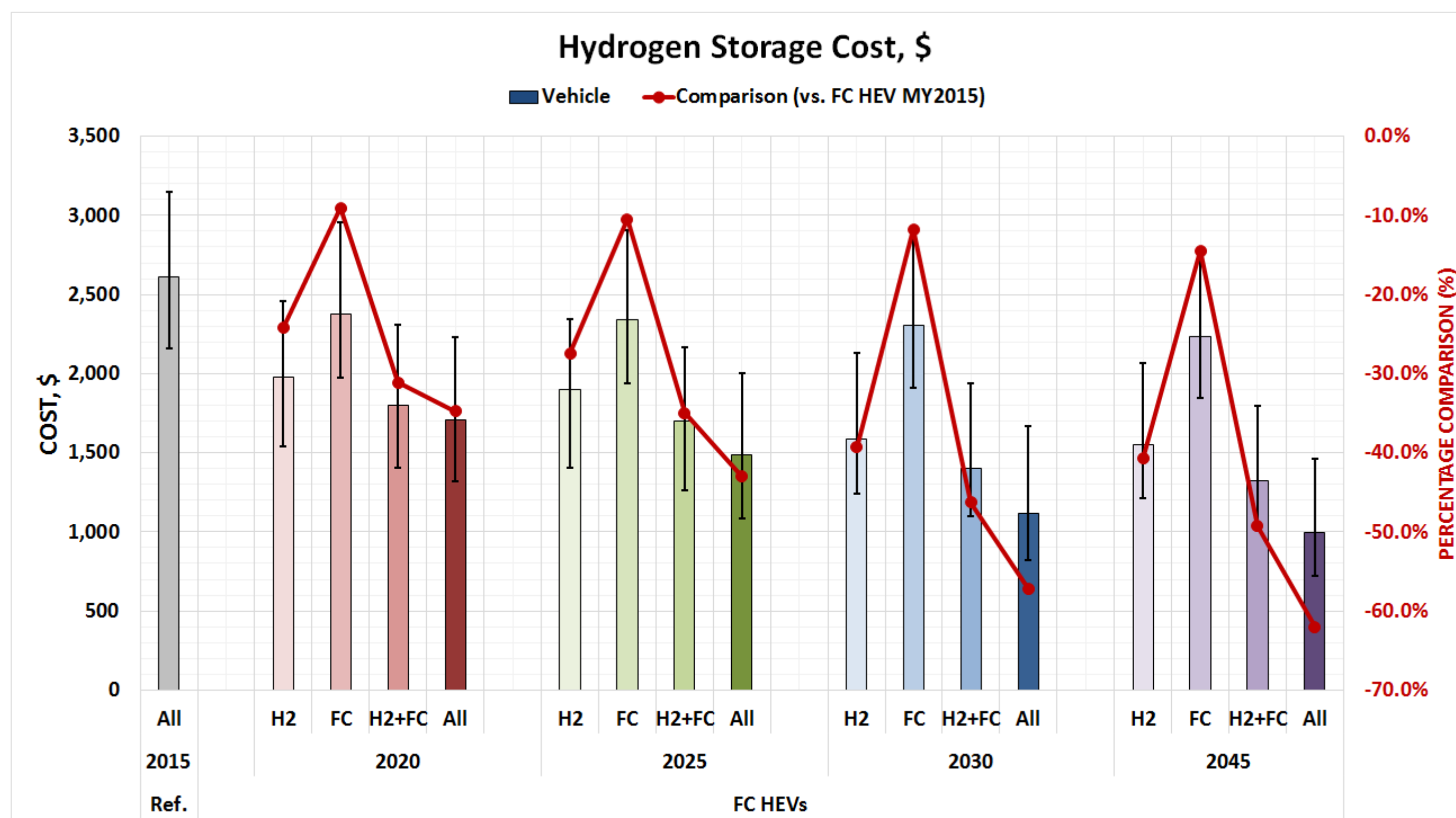


2015			
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Hydrogen Storage Cost

- Hydrogen storage cost could decrease by 40%, due to the hydrogen storage technology improvements only.



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H2 : MY2015 Midsize FC HEVs with H2 storage technology alone from that Year

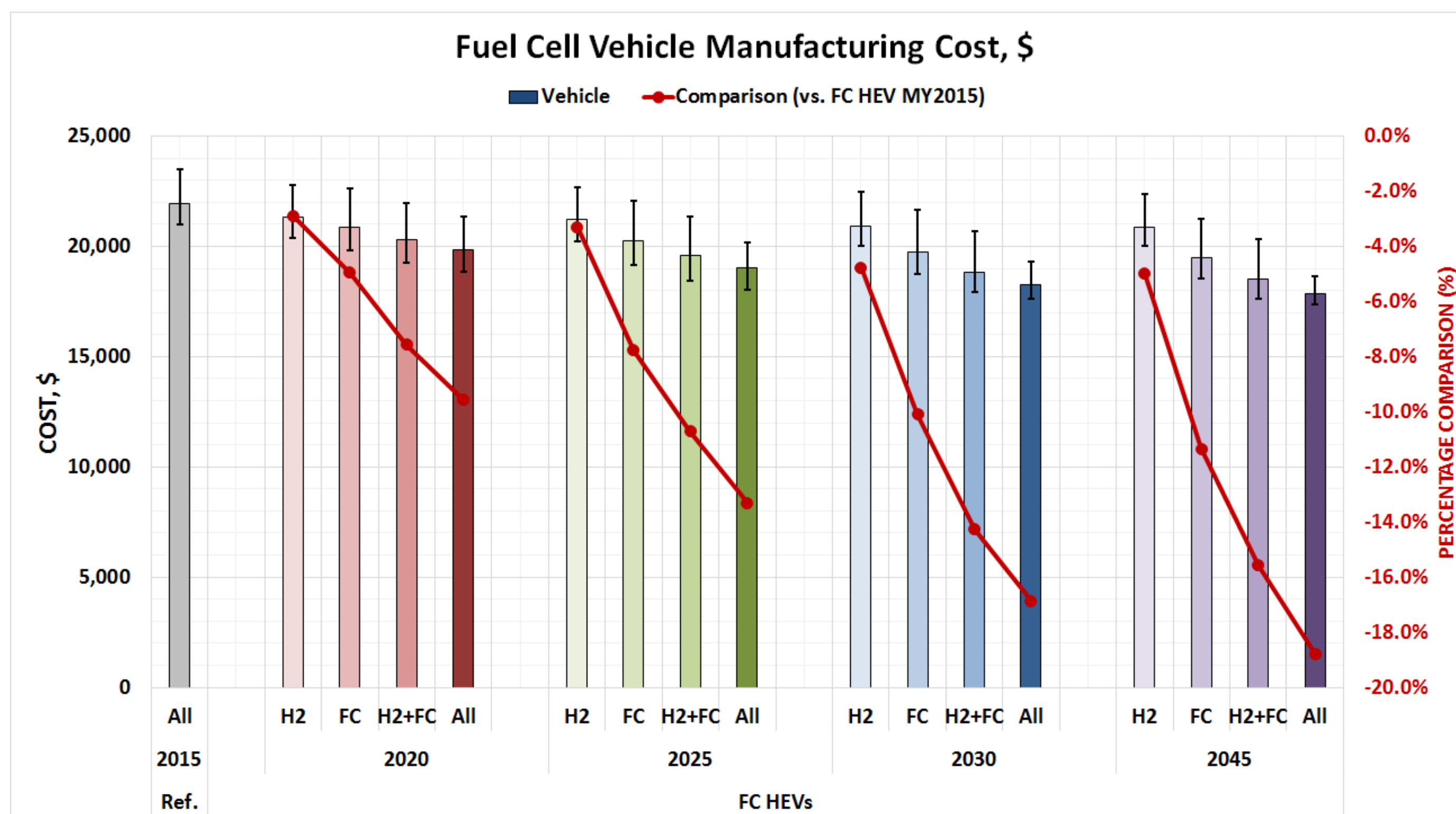
FC : MY2015 Midsize FC HEVs with FC system technology alone from that Year

H2 + FC : MY2015 Midsize FC HEVs with H2 storage + FC system technologies alone from that Year

All : Midsize FC HEVs with all technologies from that Year

Fuel Cell Vehicles Cost

- The cost decrease is mostly due to the decrease of hydrogen tank cost (up to -40%) and fuel cell system cost (up to -50%)

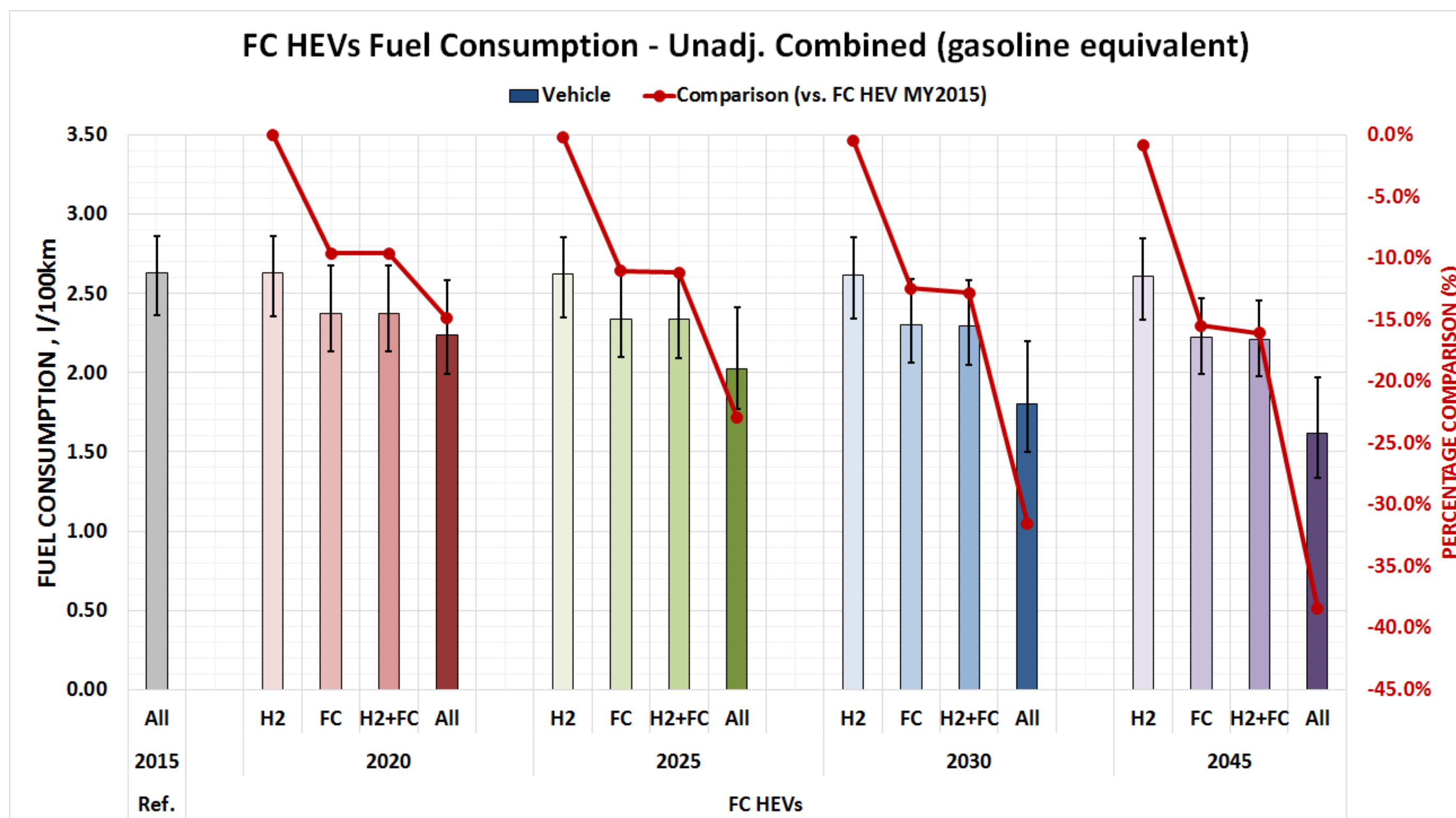


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Fuel Cell Vehicles Fuel Consumption

- Fuel cell system improvement mainly leads to significant fuel savings on the EPA combined driving procedure

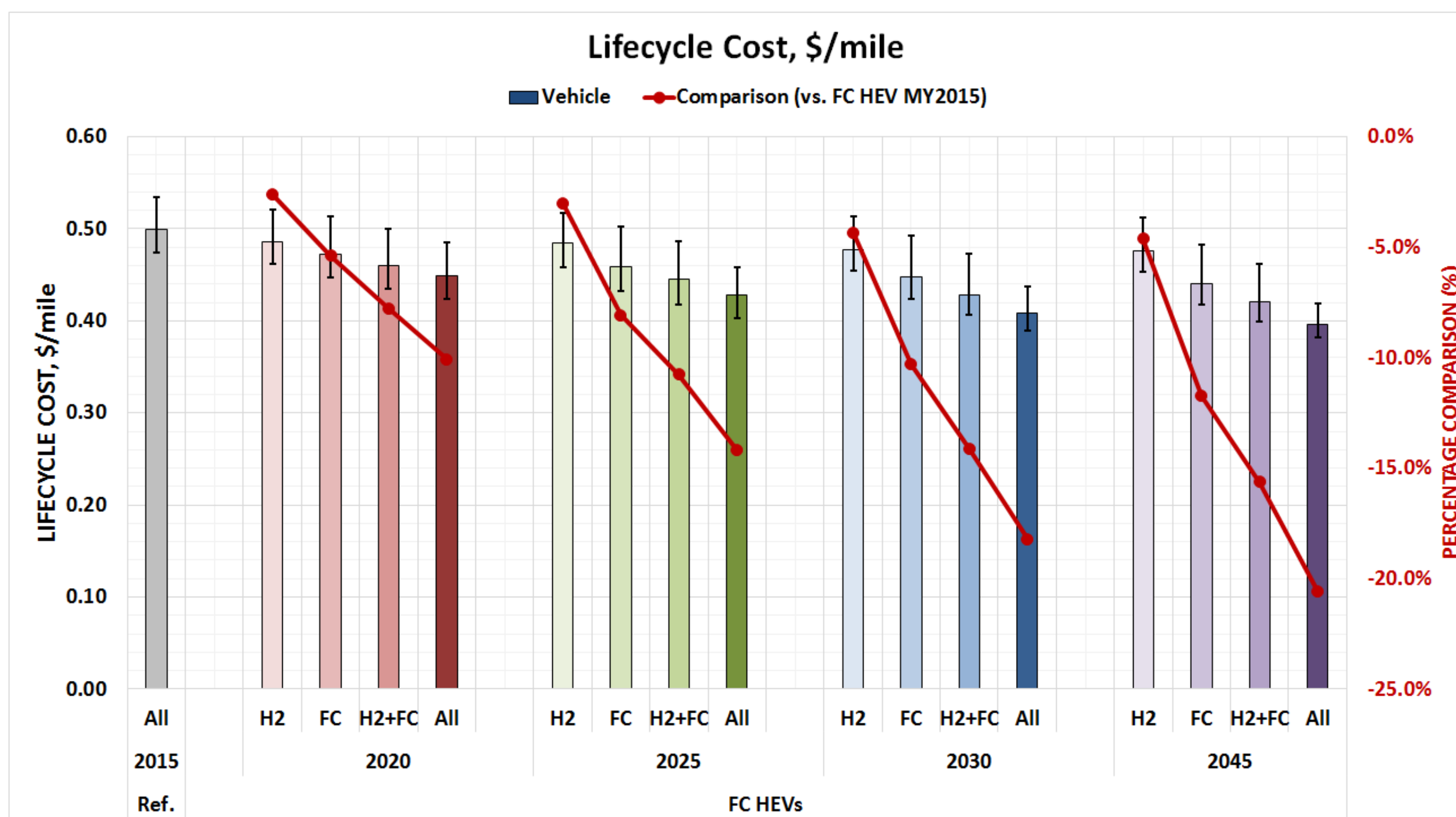


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Fuel Cell Vehicles Lifecycle Cost

- The lifecycle cost decrease is mostly due to both fuel cell system and hydrogen storage technologies improvement.

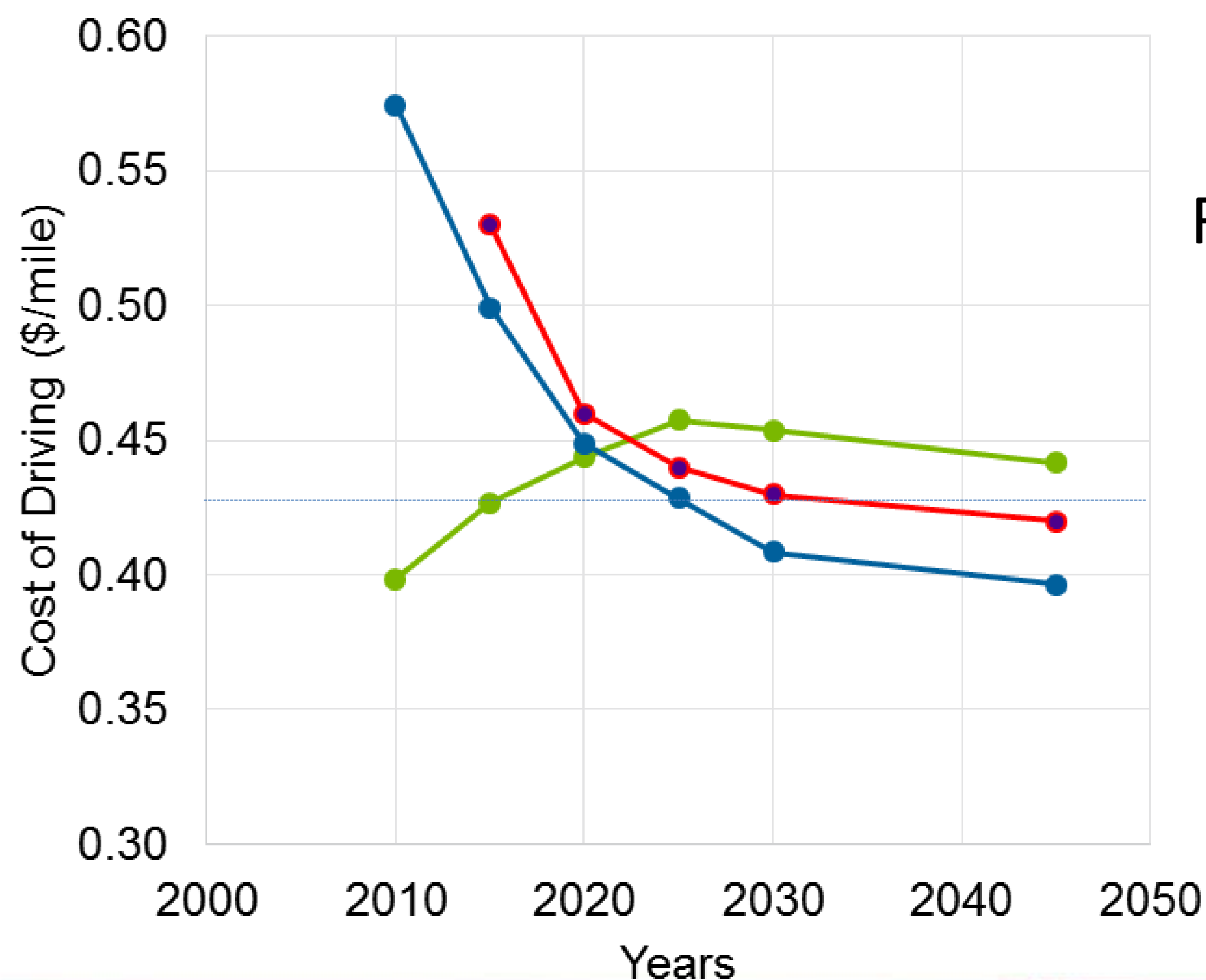


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FCEVs are Commercially Viable when Achieving Fuel Cell Program Targets

- 2015 Conventional vehicle costs about 43¢/mile.
- Achieving FC program targets makes FCEVs cost competitive by 2030
- Achieving 'all technology' targets, makes FCEVs competitive by 2025



Fuel price assumed at \$3.5/gge

- Conv SI with all technologies
- FCEV with all technologies
- FCEV without 'other' technologies

Summary

- Vehicle simulations were carried out to evaluate the benefits of fuel cells and storage without considering improvements in other technologies
- For FCEVs
 - The vehicle weight decrease is mostly due to light weighting and other components improvement.
 - The vehicle manufacturing costs decrease is mostly due to the decrease of both fuel cell system and hydrogen tank costs.
 - While better batteries, electric machine and light weighting help, fuel cell system improvement is the main contributor to fuel savings on the EPA combined driving procedure.
- For a midsize sedan, as fuel cell technologies improves in the future,
 - Fuel Cell power requirement reduced from 79kW to 76kW
 - Onboard H₂ requirement reduced from 4.9kg to 4.1kg



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Acknowledgements

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Contact / Website

Namdoo Kim, nkim@anl.gov

Aymeric Rousseau, arousseau@anl.gov

<http://www.autonomie.net/>

Argonne National Laboratory, 9700 South Cass, Argonne IL 60439, USA