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Benefits of Fuel Cell Range Extender for Medium Duty Application

Aymeric Rousseau, Phil Sharer

Presented by: R. Vijayagopal

Argonne National Laboratory, USA

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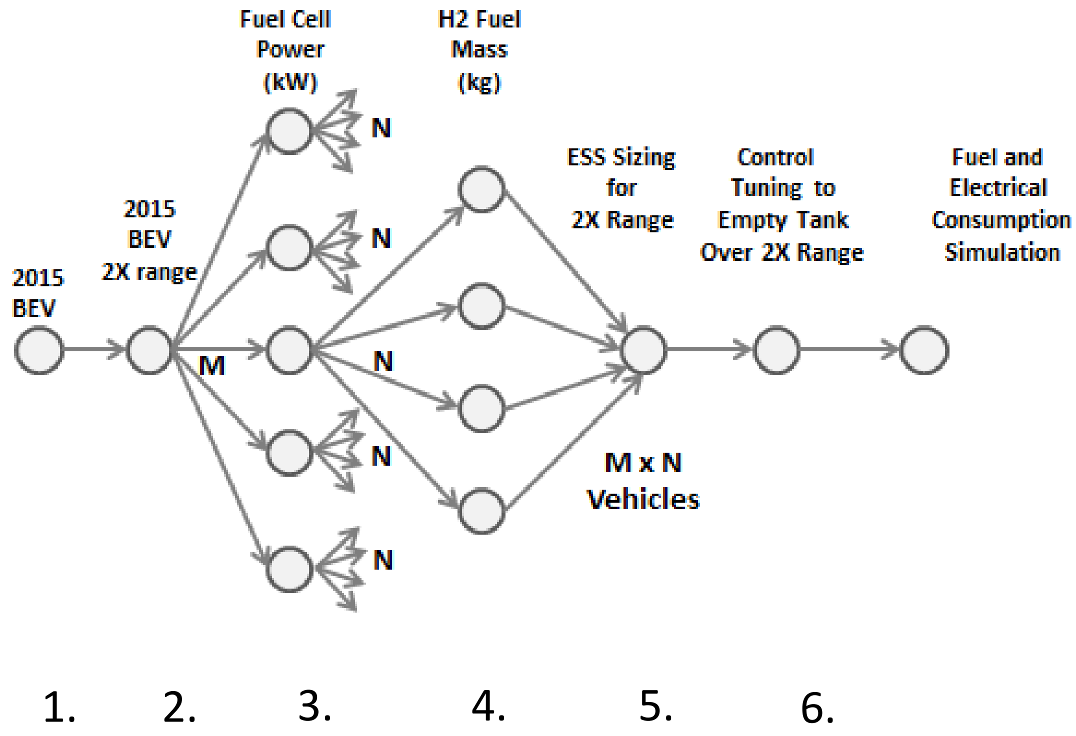
Objectives

- What is the impact of doubling the BEV range using a fuel cell range extender on the vehicle Levelized Cost of Driving (LCOD)
- What size should the fuel cell system be?
- What is the manufacturing cost benefit?
- What is the operating cost benefit?
- What effect does the addition of the fuel cell system have on vehicle mass, battery power, battery capacity and motor power?

Methodology: Parametric Sweep of Fuel Cell Power and On-Board Hydrogen

1. Define Class 4 reference BEV
2. Resize the BEV to double the AER
3. Different fuel cell stack powers were chosen (10 to 20kW every 2.5 kW)
4. For each fuel cell stack power, different amounts of on board H2 were chosen (2 to 8kg every 2kg)
5. The battery was resized (both power and energy) to account for the additional energy from the fuel cell
6. The control was tuned so that the AER range was completed with an empty tank. Fuel cell system used at its peak power.

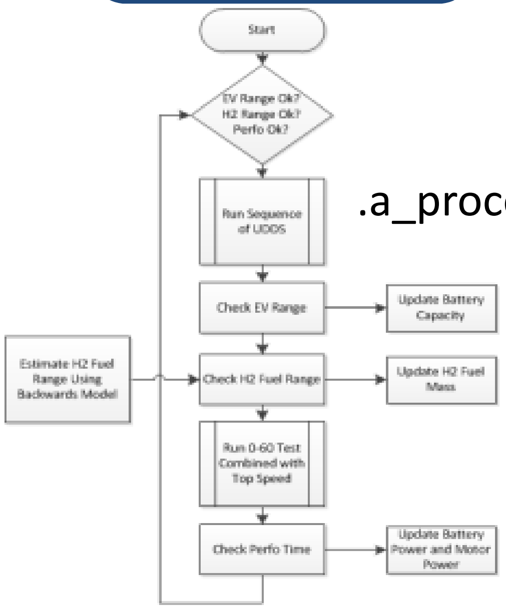


Sizing Algorithms Were then Used to Define the Vehicles and Run the Drive Cycles Using Distributed Computing

Vehicles Automatically Sized

Distributed Computing

Autonomie Postprocessing API



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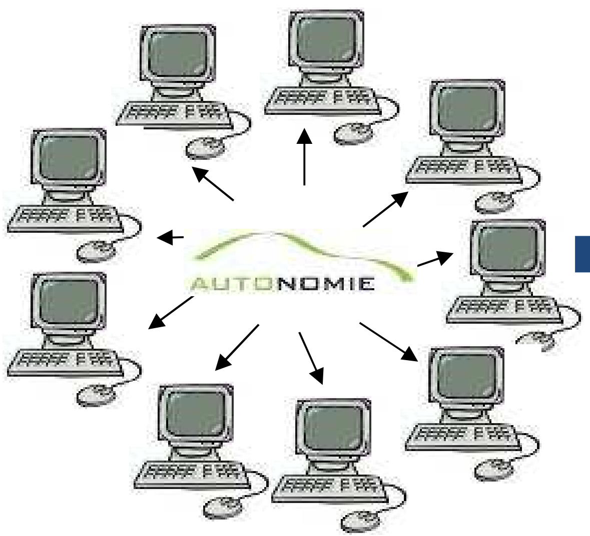
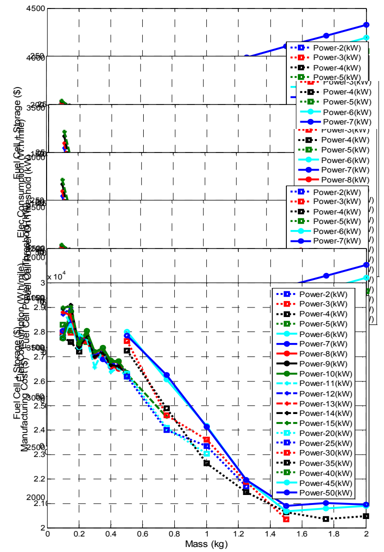




>300 individual vehicles simulated

Reference BEV Class 4 (Similar to Navistar Estar)

Assumption	Value
Vehicle test weight	3900 kg (baseline)
Transmission type	Automatic
Transmission	3.1, 1.81, 1.41, 1, 0.71
Motor type	Permanent magnet
Motor power	70 kW
Battery type	Li-ion
Battery power	345 W/cell, 83 kW/pack
Battery energy	327 Wh/cell, 80 kWh/pack
Battery capacity	84 Ah/cell
Nominal voltage	317 V
Number of cells	80 series x 3 parallel strings (240 cells/pack)
Rolling resistance	0.0075
Coefficient of drag	0.56
Frontal area	4.7500 m^2
Fuel cell APU peak eff.	60% (50% at rated power)
Fuel cell idles all the time	True
Payload	1,159 kg

Fuel Cell System and Hydrogen Storage Cost Assumptions

Fuel Cell Stack Cost

Fuel Cell Rated Power (kW)	2010 $/kW at 10,000 Units/yr	Total Cost (2010 $)
15	298.33	4,475
14	333.5	4,670
12	404.0	4,848
10	474.4	4,744
8	544.6	4,359
6	615.3	3,692
5	650.51	3,253

Hydrogen Storage Assumptions 700 bar

Fuel Cell Rated Energy (kg)	2010 $/kWh at 10,000 Units/yr	Total Cost (2010 $)
4.0	12.29	1,639
3.0	13.13	1,313
2.0	14.52	968
1.0	19.08	636
0.5	28.05	468

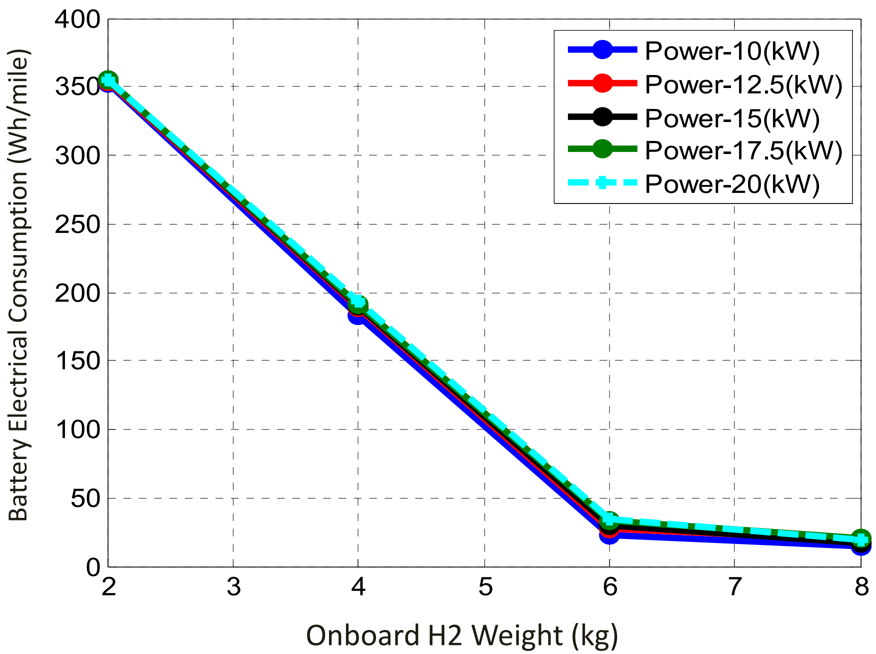
Source – Strategic Analysis – Current cost at 10,000 units/year

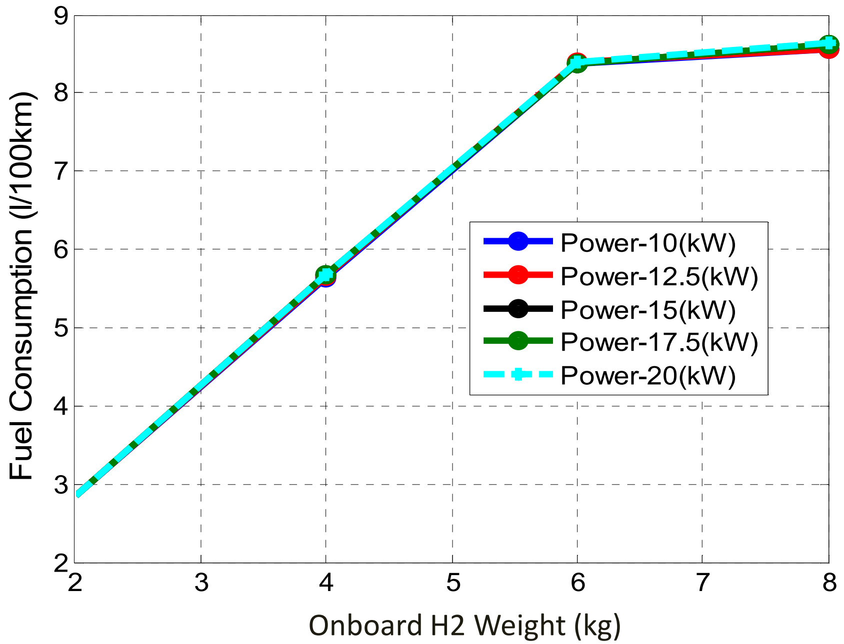
Levelized Cost of Driving Assumptions

Assumption	Value
Time frame	2015
Vehicle lifetime	5 years
Carbon cost per mile	0
Noncapital cost per mile	0
Charger efficiency	88%
Discount rate	0
Retail price equivalent	1.5
Annual miles traveled	14,529 mi
Fuel hydrogen	$3.50/gge
Electricity cost	$0.11/kWh
NPV fuel and electricity combined discount factor	1

The Electrical Consumption Decreased Proportionally as Fuel Consumption Increased Until 6 kg of H2

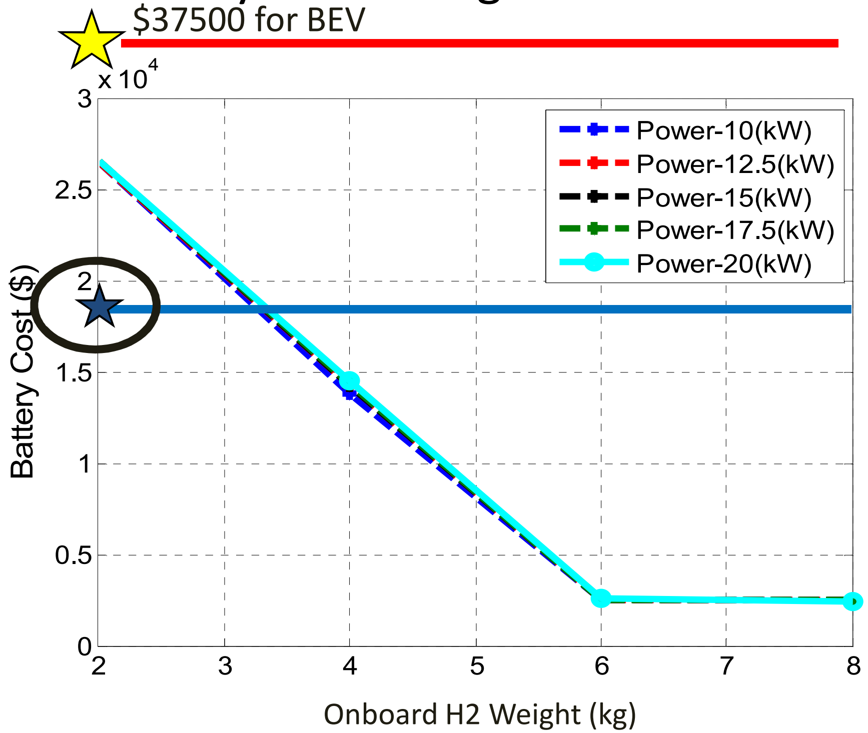
- The electrical energy consumption was close to zero with 6kg of H2.
- The addition of more energy forced the range out of bounds.

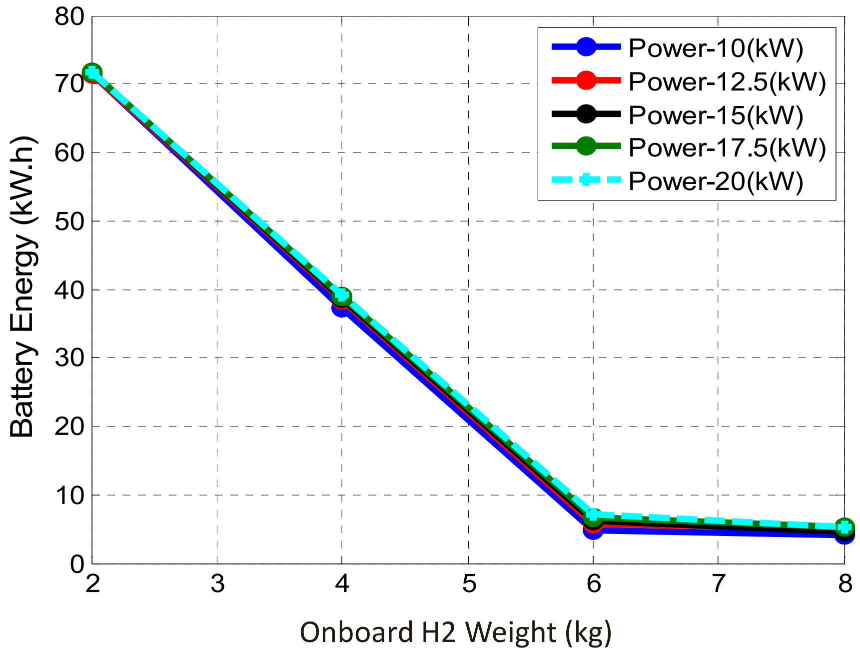




Battery Cost Decreased by 80% While Energy Decreased to Less than 10kWh

- The battery transitions from a high energy to a high power battery. Basically, the fuel cell at this value is supplying the average load on the vehicle while the battery is handling transients.

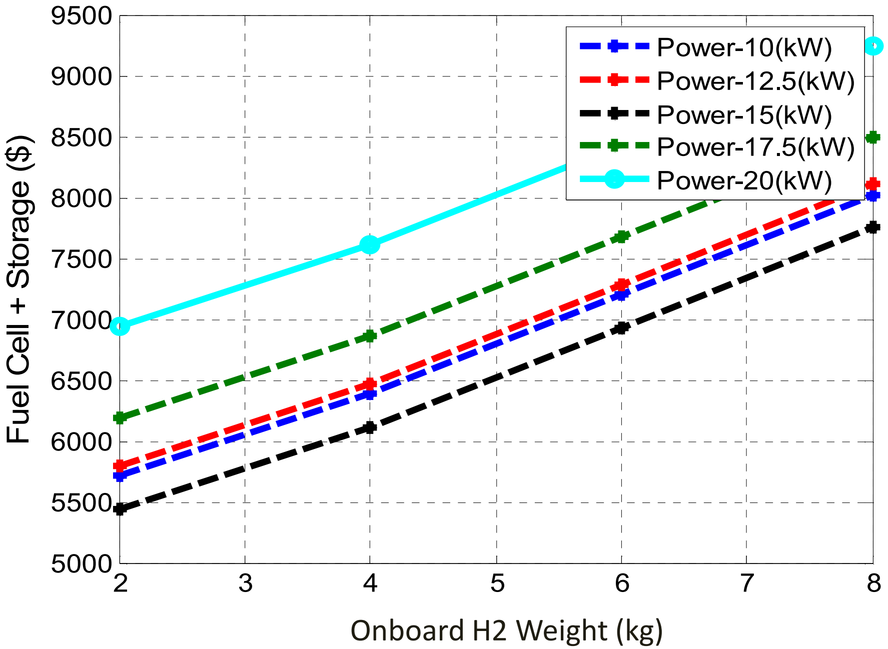


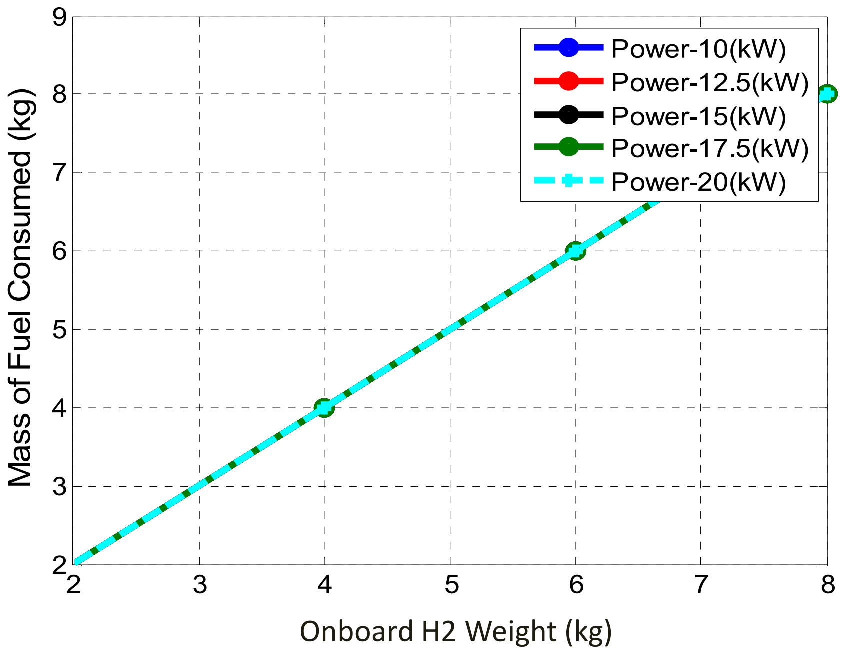


★ Cost of 2X ranged BEV Vehicle based on 250 $/kWh for battery

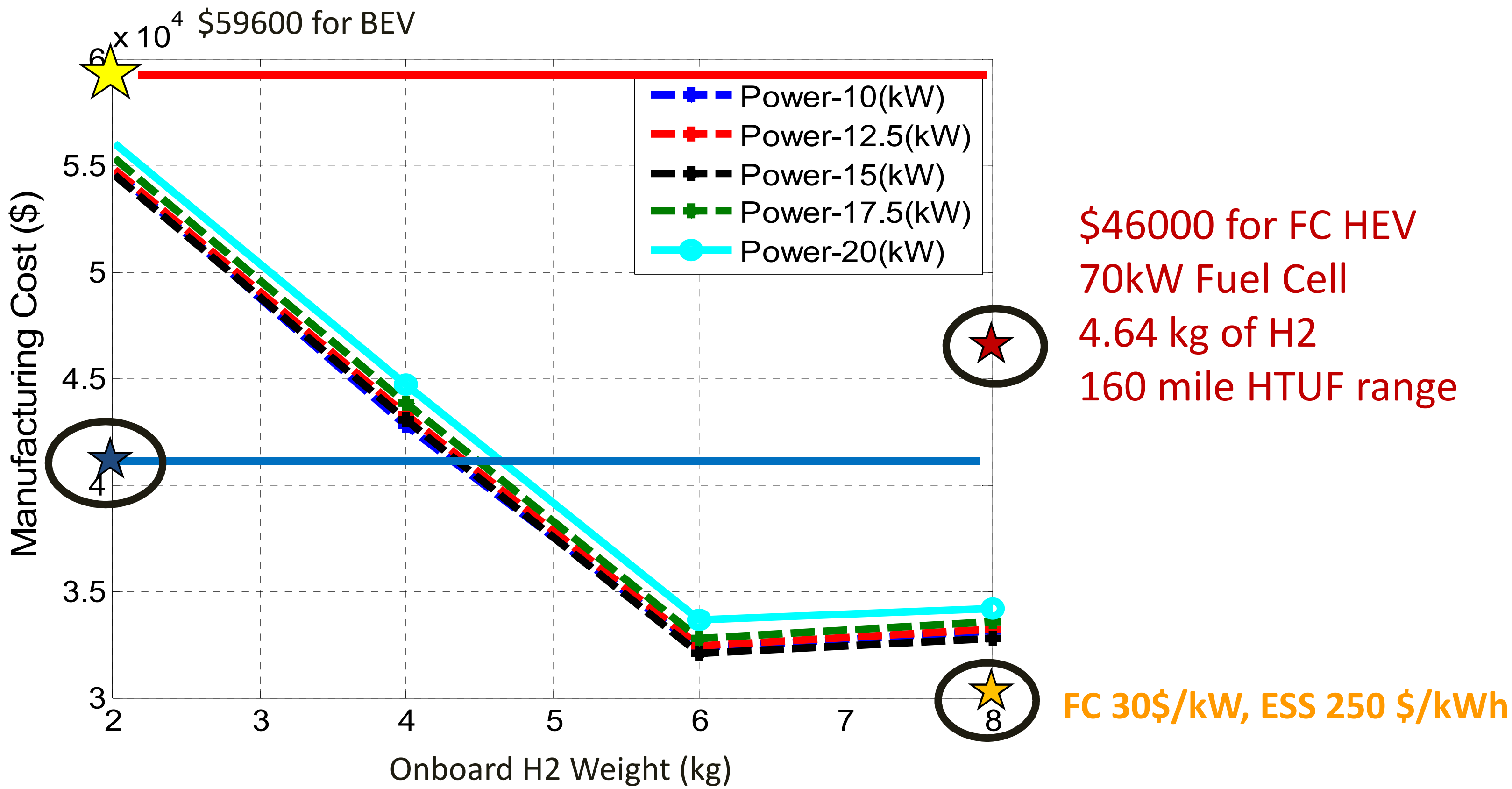
★ Cost of 2X ranged BEV Vehicle based on 500 $/kWh for battery

The Cost of Fuel Cell System and its Storage Increases by $2500 when Increasing the H2 Weight from 2 to 8kg





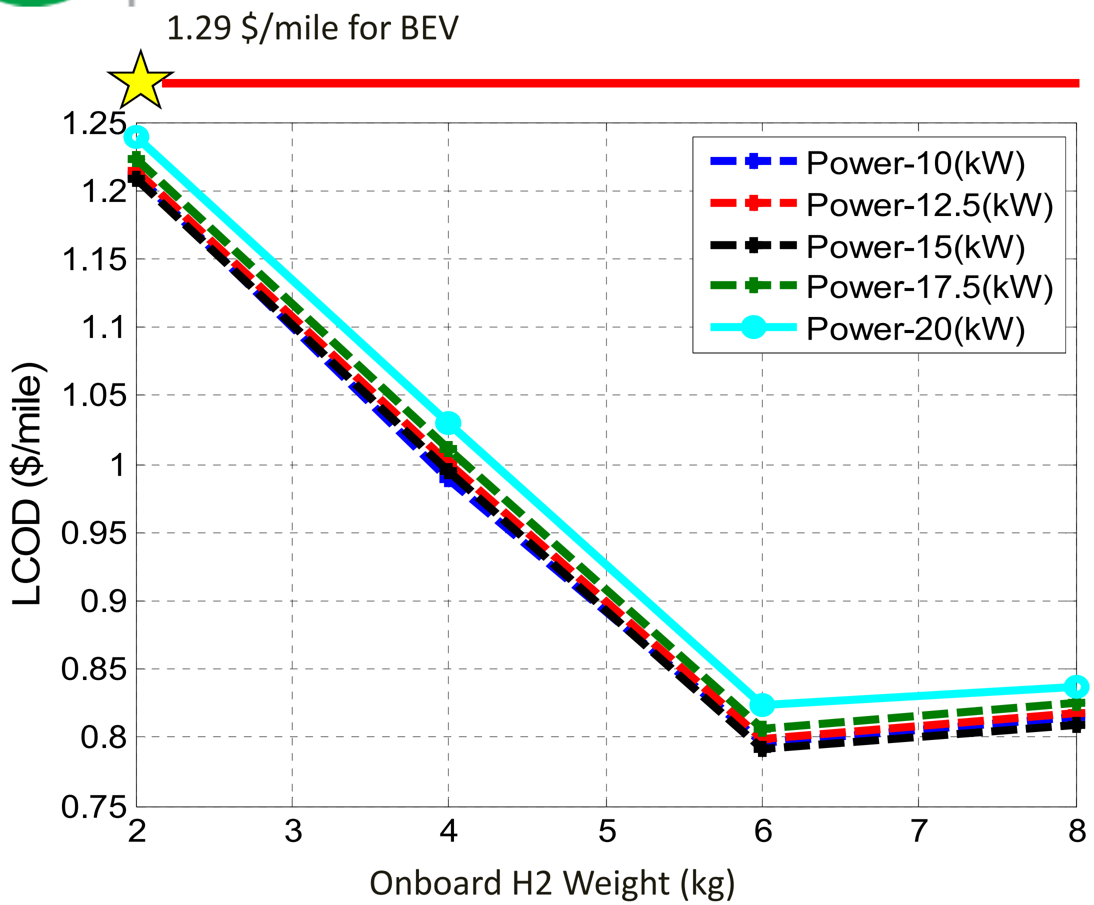
The Total Manufacturing Cost Saving is Close to $11500



★ Cost of 2X ranged BEV Vehicle based on 250 $/kWh for battery

☆ Cost of 2X ranged BEV Vehicle based on 500 $/kWh for battery

Levelized Cost of Driving Decreased by 40% with 6 kg of H2



☆ Cost of 2X ranged BEV Vehicle based on 500 $/kWh for battery

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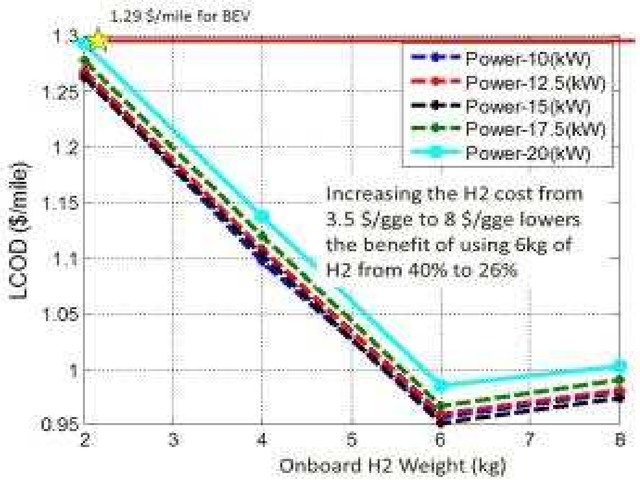
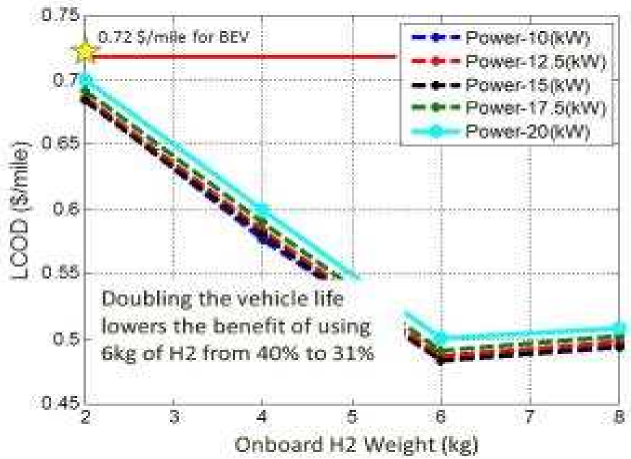
Impact of Cost Assumptions on Fuel Cell Range Extender Benefits

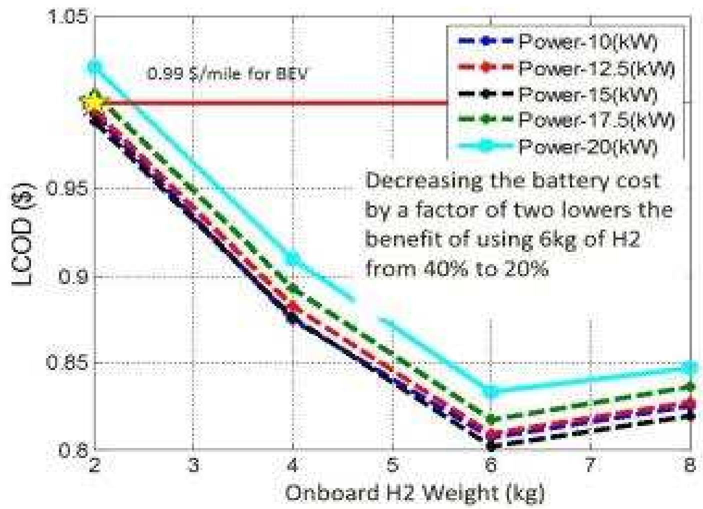
500 $/kWhr, 8 $/gge, 5 year/lifetime, 15Kmile/year



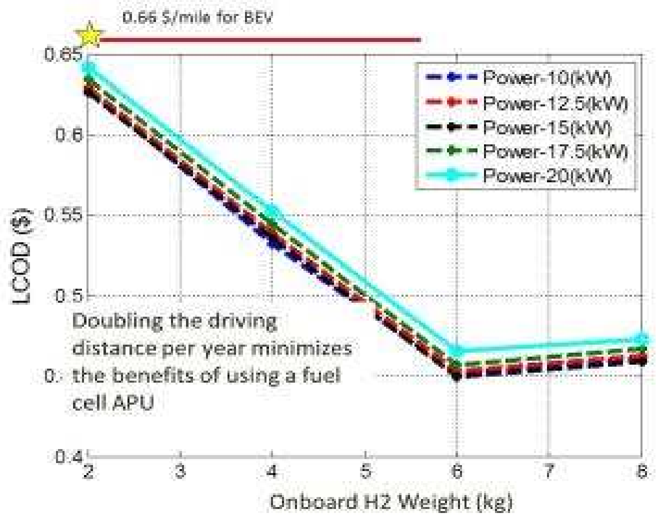
500 $/kWhr, 3.5 $/gge, 10 year/lifetime, 15Kmile/year



250 $/kWhr, 8 $/gge, 5 year/lifetime, 15Kmile/year



500 $/kWhr, 3.5 $/gge, 10 year/lifetime, 30Kmile/year



Fuel Cell Range-Extender Shows Great Cost Reductions Promises to Double the Range of Current BEVs

- Based on the cost assumptions and drive cycle considered:
  - Fuel Cell is cheaper than a battery to storage energy
  - Battery is cheaper than a fuel cell to deliver power
  - Using the fuel cell close to its rated power (i.e., maximum power control) would provide the lowest LCD
  - For the drive cycle considered, a 10-20 kW fuel cell system with 6 kg of H2 would provide a good solution
  - The fuel cell range extender option consistently reached a lower LCOD when compared with a BEV with twice the original electric range when the cost of the fuel cell was considered at a production level of 10,000 units.
- The results are impacted by H2 cost, vehicle life, driving distance, battery cost… However, the fuel cell range extender option consistently reaches a lower LCD compared to a BEV with twice the original electric range

Acknowledgments

- We would like to thank Pete Devlin from the U.S. Department of Energy (DOE) for supporting the study as well as Strategic Analysis for providing fuel cell system and hydrogen storage cost assumptions.