Fuel Cells as Range Extenders for Battery Electric Vehicles

2013 DOE Hydrogen Program and Vehicle Technologies Annual Merit Review

May 15th, 2013

Phil Sharer, Aymeric Rousseau

Argonne National Laboratory

Sponsored by Pete Devlin

Project ID # MT012

U.S. Department of Energy
Energy Efficiency and Renewable Energy
Bringing you a prosperous future where energy is clean, abundant, reliable, and affordable

Project Overview

Timeline	Barriers
Start Date: July 2012 End Date: March 2013 Percent Complete: 100%	• Evaluate energy and cost benefits of H2 FC technologies • Suite of Models and Tools • Unplanned Studies and Analysis

Budget	Partners
Total Project Funding • DOE share: $200,000 • Contractor share: none	Formal Collaborator • Strategic Analysis (provided fuel cell and hydrogen storage cost) Interactions • Multiple reviews with OEMs and other National Laboratories

Relevance

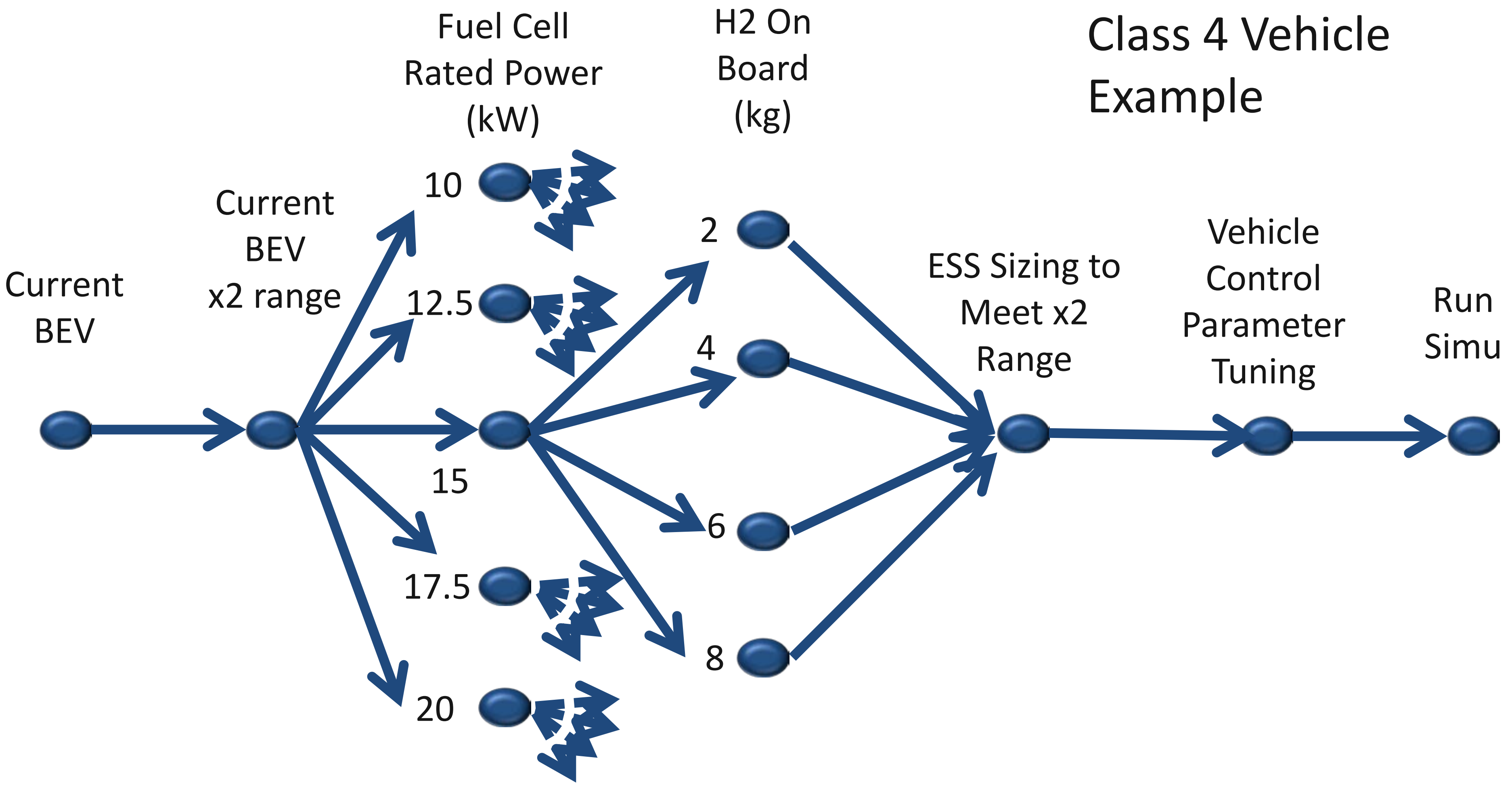
The objective is to evaluate the potential of using a fuel cell system to double the range of current Battery Electric Vehicles

- Does a fuel cell range extender hold promise to cost effectively extend the range of a battery electric vehicle?
- What size should the fuel cell system and hydrogen storage be?
- What are the manufacturing and operating cost impacts?
- What effect does the addition of the fuel cell system have on vehicle mass, battery power, battery capacity and motor power?
- Is the benefit the same for all vehicle platforms?

Approach

- Two vehicle platforms were selected
  - Compact (Similar to Nissan Leaf®)
  - Class 4 HD (Similar to Navistar® Estar™)
- Fuel Cell system and hydrogen storage costs based on current technologies & 10,000 units production
- Vehicle components were sized to double the initial BEV range
- Vehicle control parameters set to use the fuel cell throughout the entire range
- Various control options considered
  - Load following
  - Thermostat
    - Demanded power at max power
    - Demand power at optimal power
    - Demanded power at 50% power

Approach
Large Number of Combinations Considered



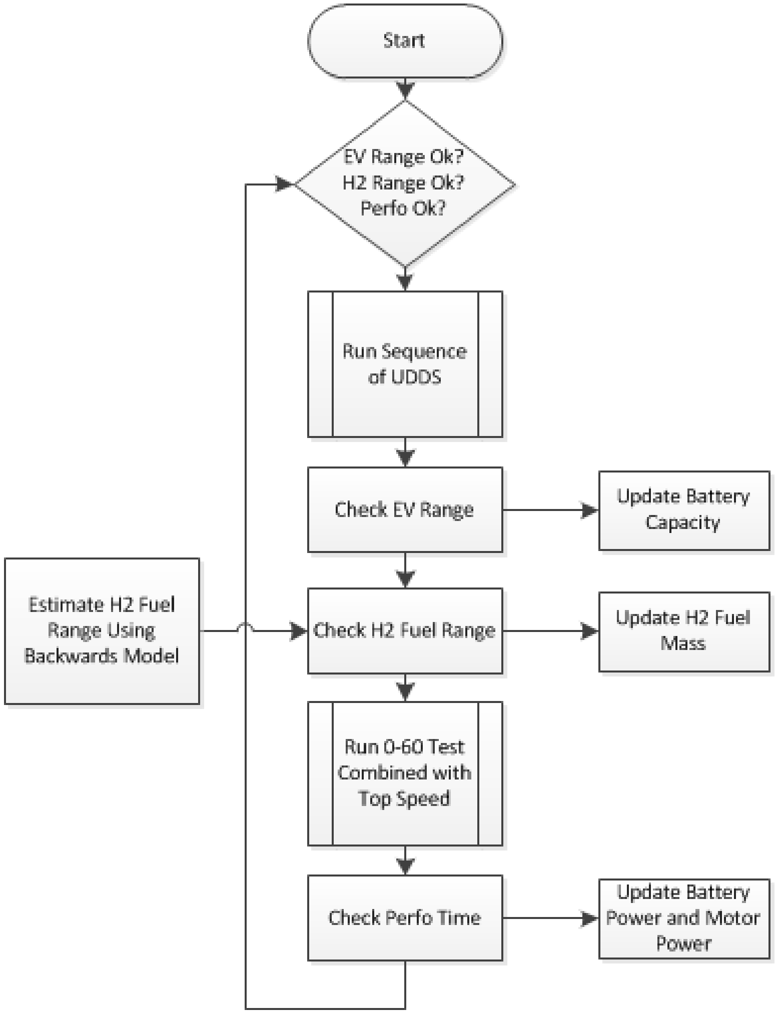
2 BEV + 5 Fuel Cell rated Power * 4 H2 On Board = 22 Vehicles
All vehicles sized to meet similar Vehicle Technical Specifications

Approach

For Each Control Strategy, Specific Automated Sizing Algorithms were Developed

Objective is to define:

- Fuel Cell Power
- H2 weight
- Battery Energy
- Vehicle level control parameters



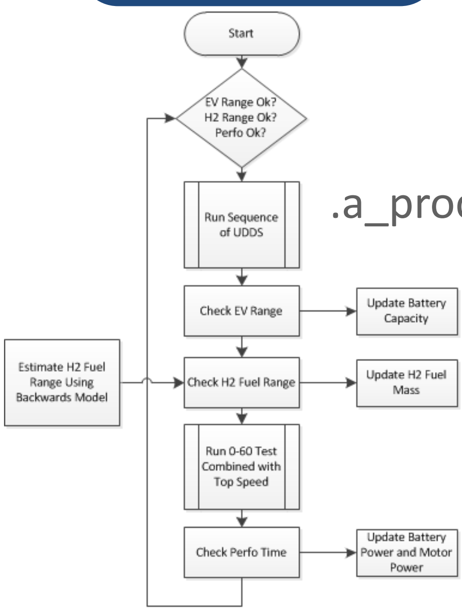
Approach

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

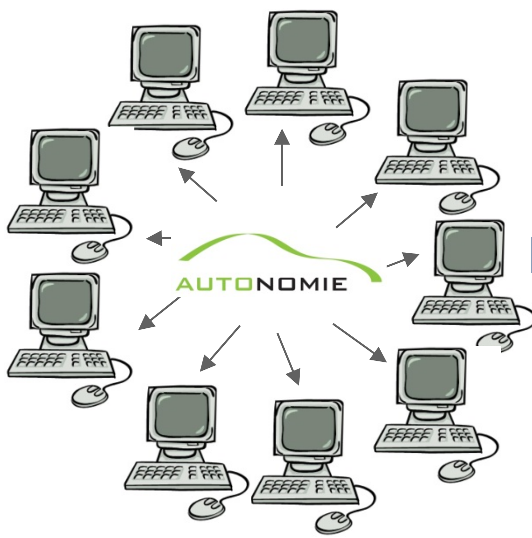
Vehicles Automatically Sized

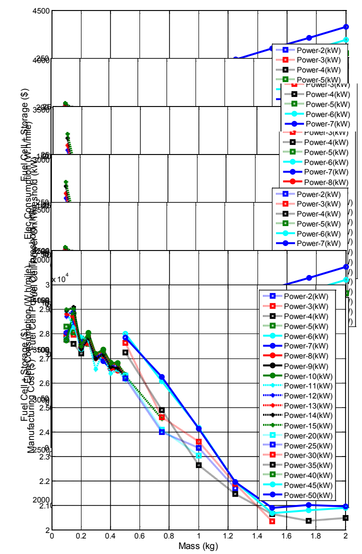
Distributed Computing

Autonomie Post-processing API

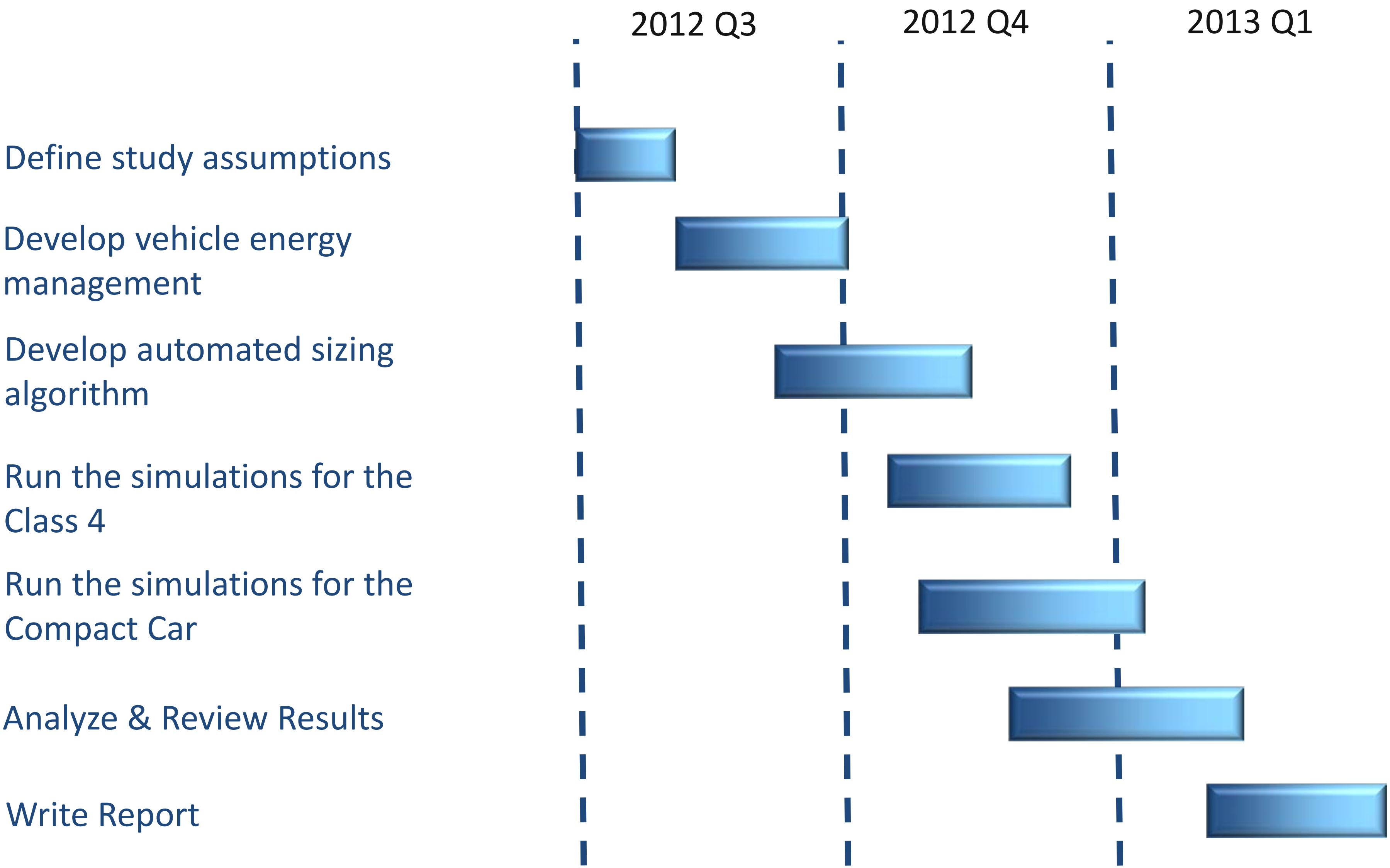


.a_process





Milestones

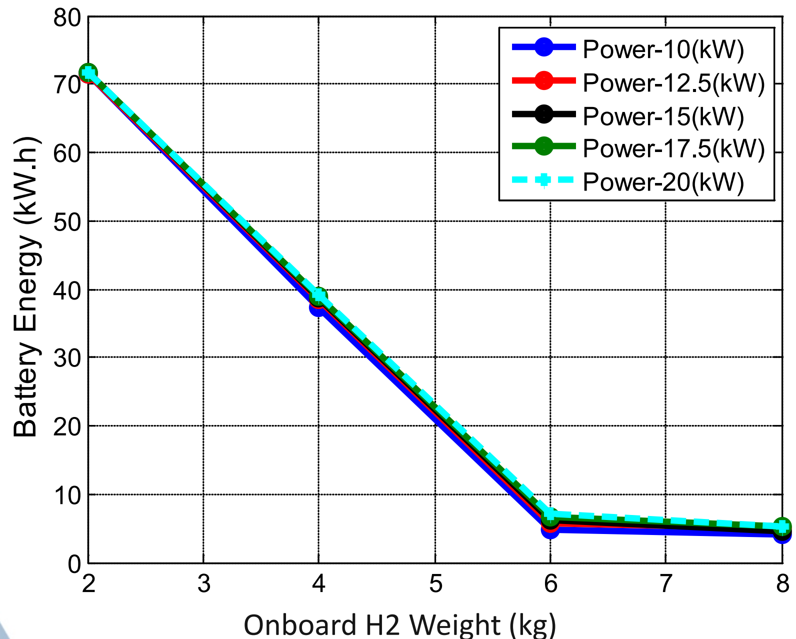

2012 Q3
2012 Q4
2013 Q1
Define study assumptions
Develop vehicle energy management
Develop automated sizing algorithm
Run the simulations for the Class 4
Run the simulations for the Compact Car
Analyze & Review Results
Write Report

Technical Accomplishments

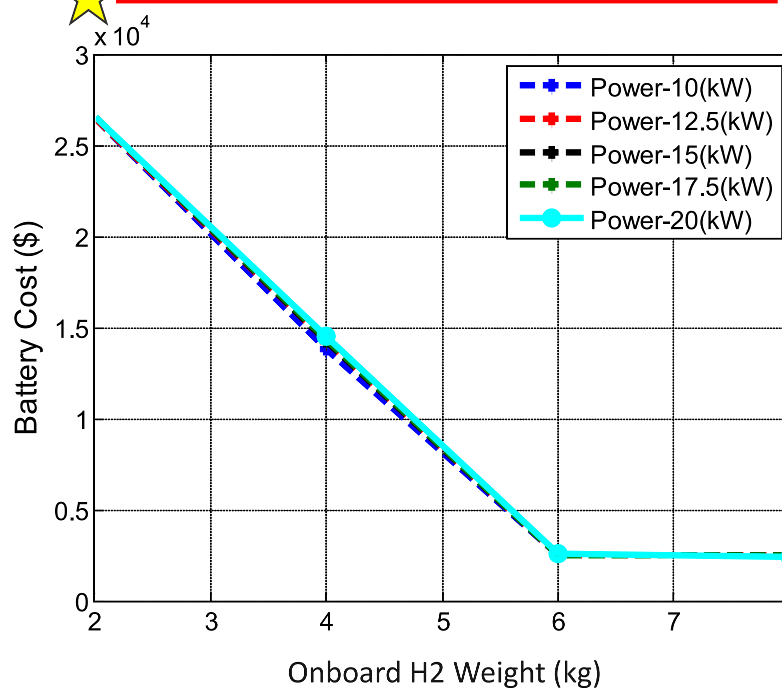
Battery Cost Decreased by 80% While Energy Decreased to Less than 10kWh

- Increased onboard hydrogen fuel leads to smaller battery energy to maintain a constant range
- The battery transitions from a high energy to a high power battery (the fuel cell at this value is supplying the average load on the vehicle while the battery is handling transients)

☆ 106 kWh for BEV



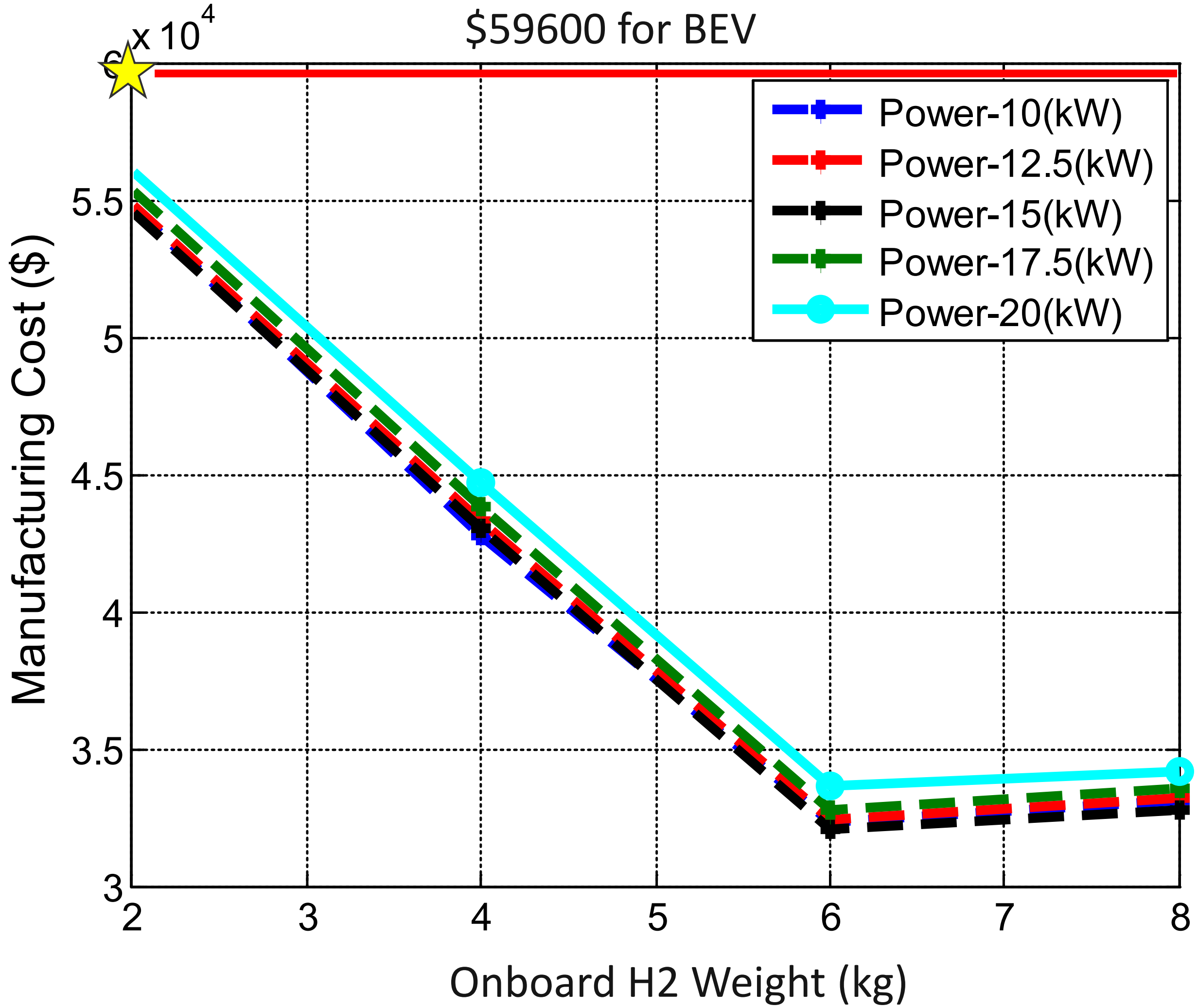
☆ $42000 for BEV



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

Technical Accomplishments

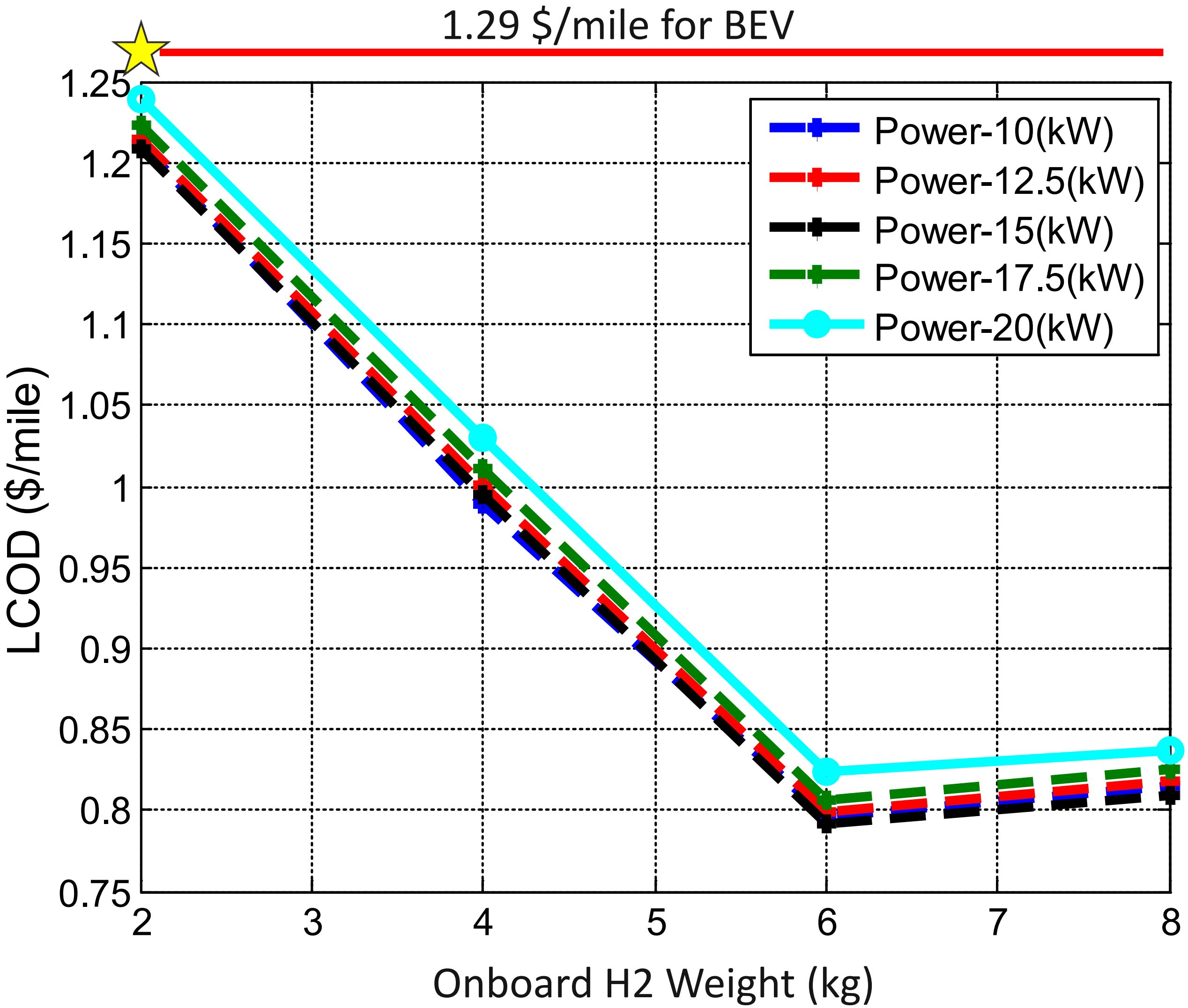
Total Manufacturing Cost Saving Up to $25,000



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

Technical Accomplishments

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



Main Parameters	Value
H2 Fuel	3.5 $/ge
ESS Cost	500$/kWh
Vehicle Life Time	5 years
Annual Miles	14,500 miles

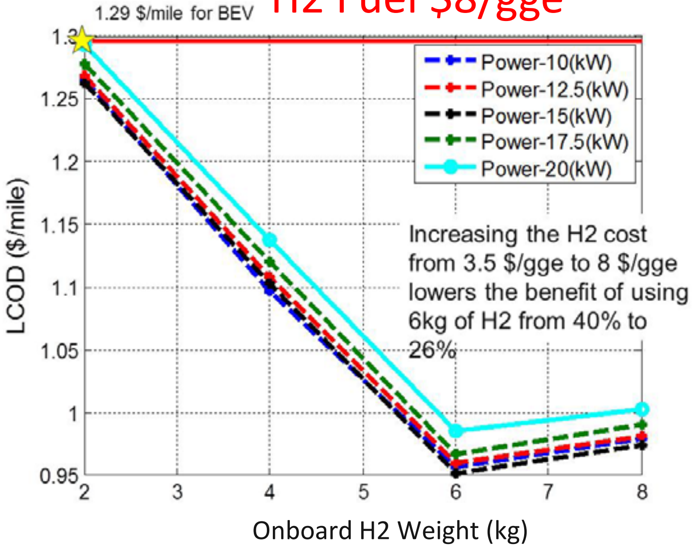
(*) Maintenance and resale not included

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

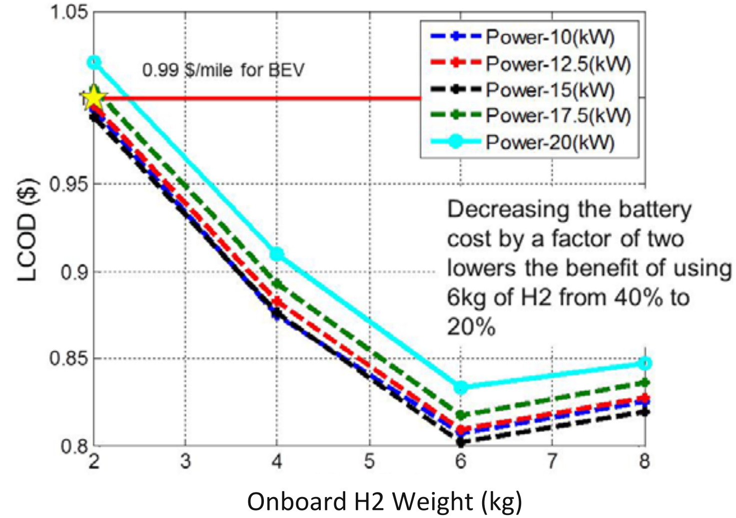
Technical Accomplishments

Uncertainty Analysis Demonstrates Robustness of Benefits

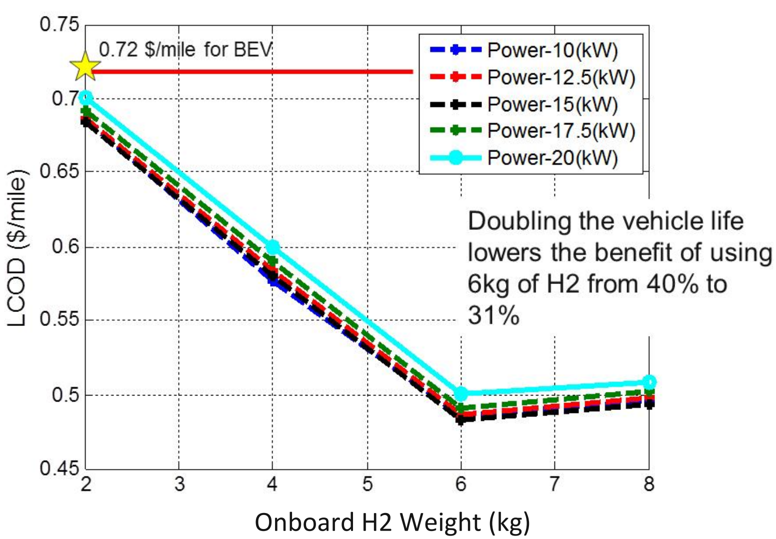
H2 Fuel $8/gge



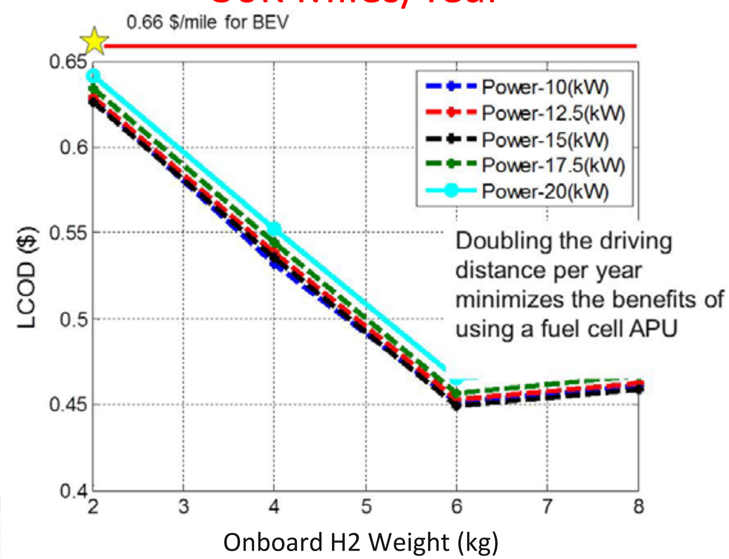
ESS 250$/kWh



10 years Lifetime



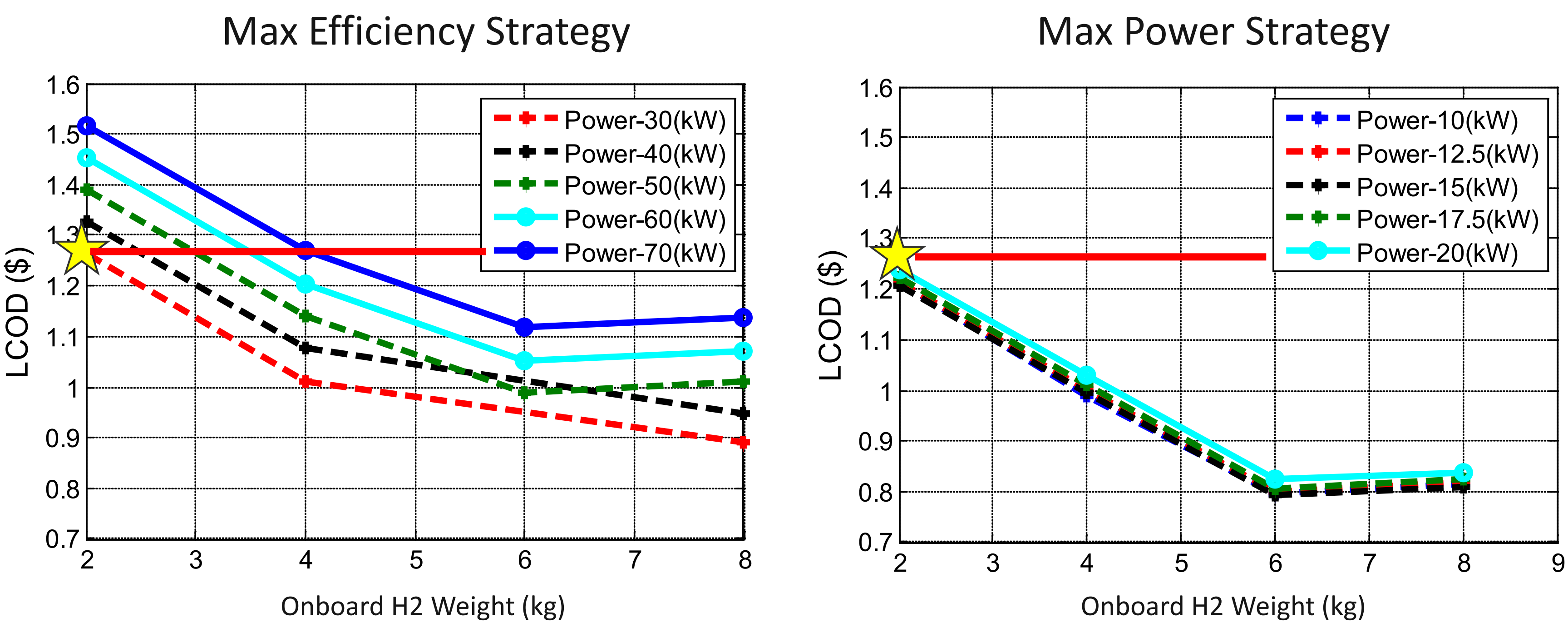
30K Miles/Year



Technical Accomplishments

Using the Fuel Cell System Close to its Peak Efficiency Decreases the Benefits

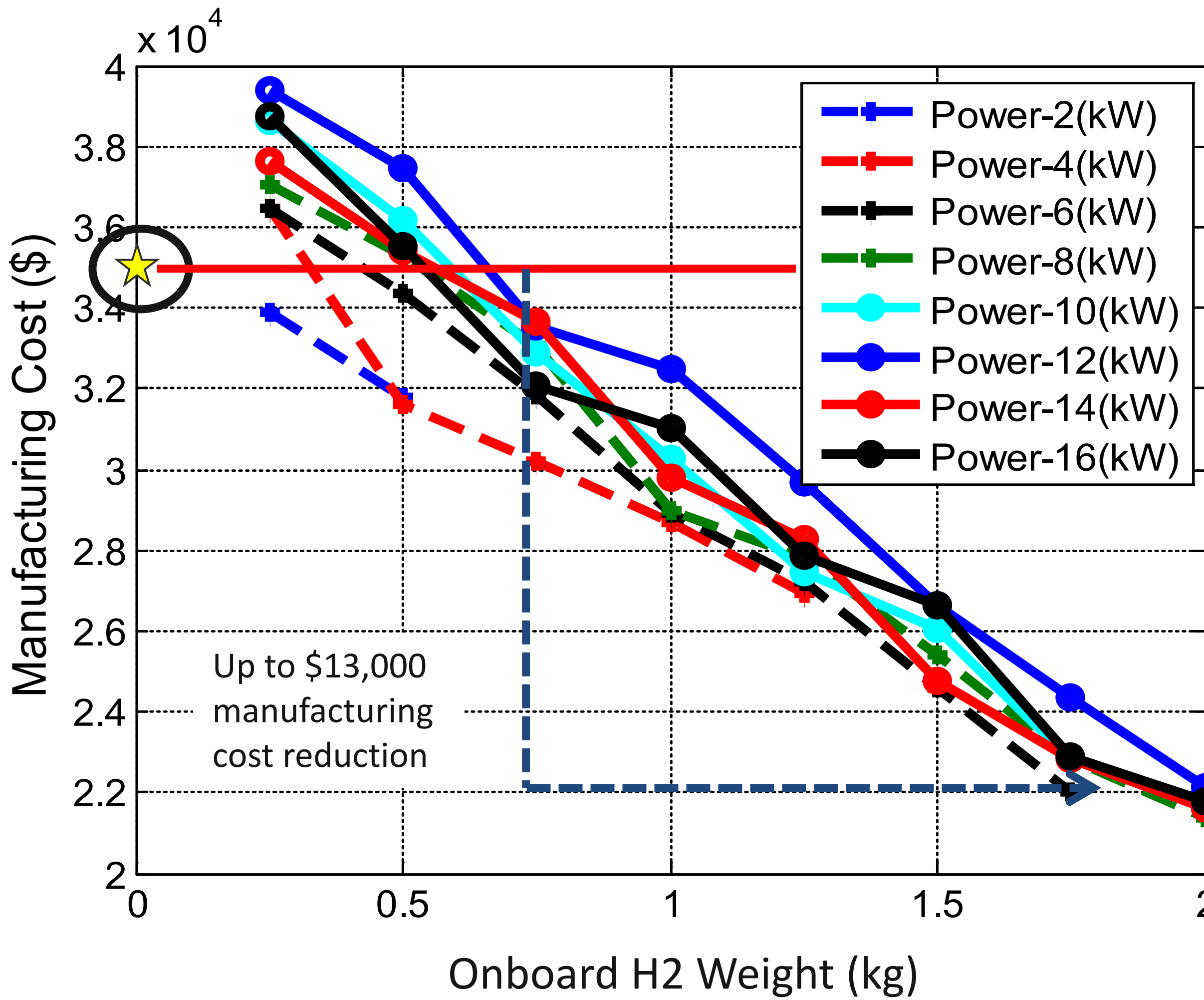
- The more expensive upfront cost of the larger fuel cell is not recovered through fuel savings by operating the fuel cell more efficiently.



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

Technical Accomplishments

Extending the Range of a Compact Car Leads to Lower Benefits Than for a Class 4 P&D

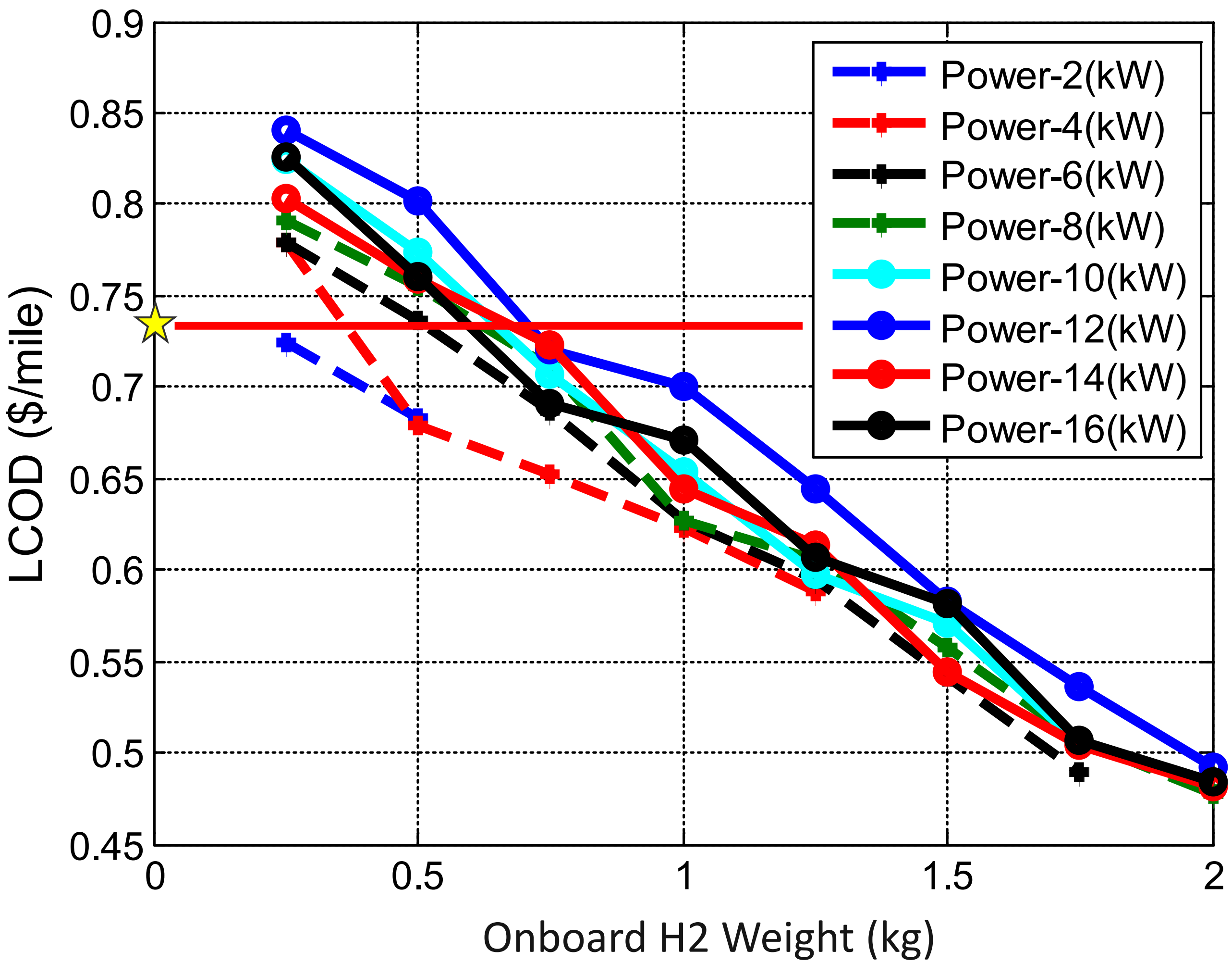


☆ Cost of 2X range BEV Vehicle based on 500 $/kWh for battery

Technical Accomplishments

Compact Car

Component and Controls Have to Be Carefully Selected to Achieve a Better LCD for Compact Cars



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

Collaboration and Coordination with Other Institutions

Component Performance, Other Costs and LCD

Fuel Cell System and Hydrogen Storage Manufacturing Cost

Results provided to OEMs and other National Laboratories involved in similar activities. Results will be used for an RFI.

Proposed Future Work

- Evaluate the impact of additional driving cycles (i.e. various distances, driver aggressiveness…) on optimum component size, on-board hydrogen and control.
- Evaluate the impact of the vehicle energy management on fuel cell system durability.
- Evaluate the potential of additional vehicle classes.
- Assess the potential of the technology for 2015, 2020 using DOE targets.
- Validate the study outcomes using fuel cell hardware-in-the-loop

Summary

- Based on the cost assumptions and drive cycle considered:
  - Fuel Cell is cheaper than a battery to store 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
    - For the compact car, a 4-8 kW fuel cell system with 2kg of H2 would provide optimum solution
    - For the Class 4, a 10 kW fuel cell system with 6 kg of H2 would provide optimum solution
- The results are impacted by H2 cost, vehicle life, driving distance, battery cost… However, the fuel cell APU option consistently reaches a lower LCD compared to a BEV with twice the original electric range