Project ID # SA044

Cost Benefits Analysis of Technology Improvement in Light Duty Fuel Cell Vehicles

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Argonne National Laboratory

2018 DOE Hydrogen Program and Vehicle Technologies Annual Merit Review

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Project Overview

Timeline	Barriers
• Project start date : Sep 2017 • Project end date : Aug 2018 • Percent complete : 80%	• Lack of Fuel Cell Electric Vehicle and Fuel Cell Bus Performance and Durability Data (A) • Hydrogen Storage (C) http://energy.gov/sites/prod/files/2015/06/f23/fcto_myrdd_tech_valid.pdf
Budget	**Partners**
• FY18 Funding : $75,000 • Percent spent : 80%	• Argonne Fuel Cell Team

Objectives

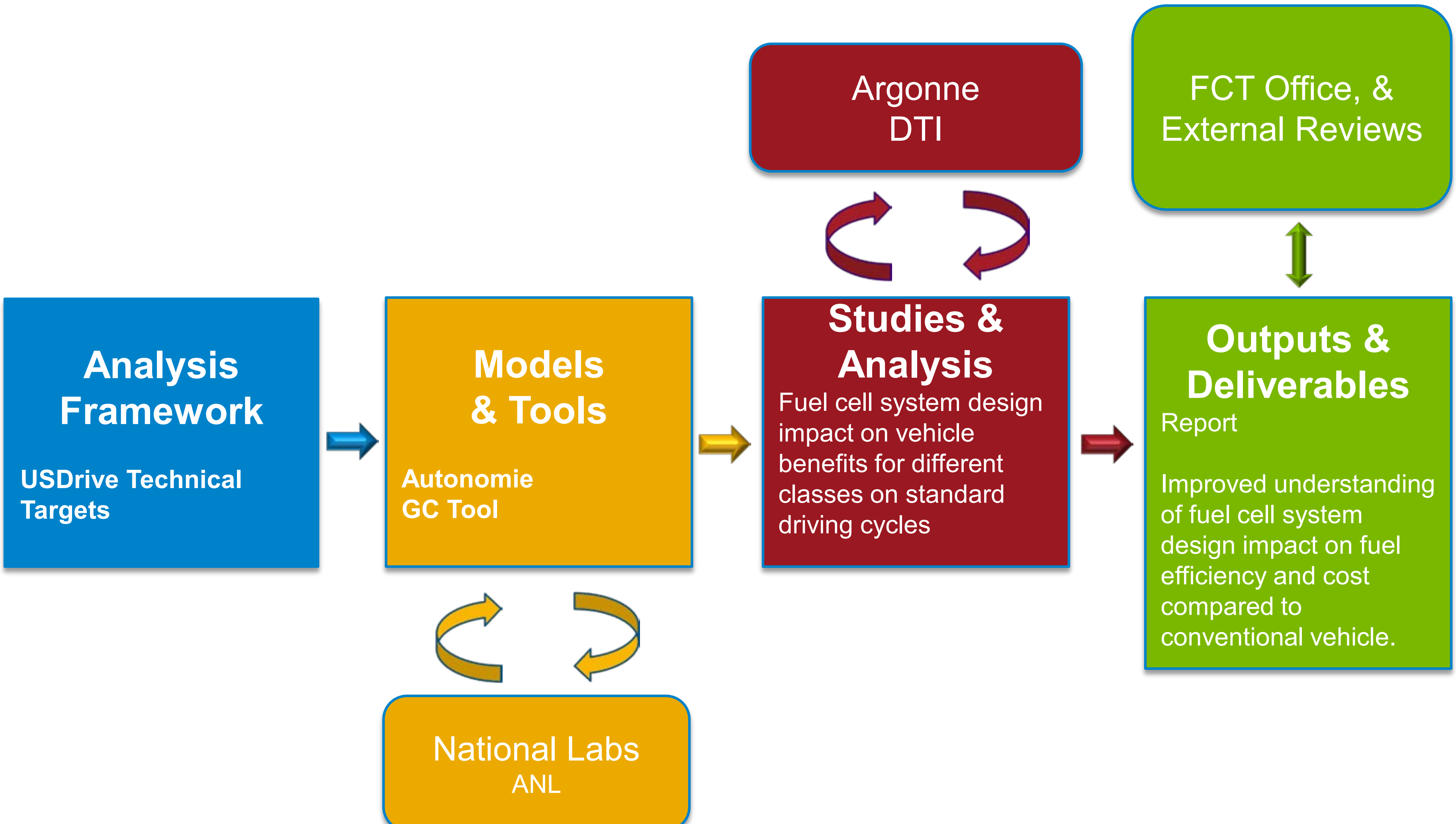
Evaluate FCEVs competitiveness, and determine the economic viability of additional technology improvements

1. Quantify individual and collective impact of fuel cell and hydrogen storage technologies on light duty vehicles (LDV) energy consumption and cost.
   a) Consider current & future technology development scenarios including uncertainties
   b) Determine fuel cell electric vehicles (FCEVs) cost of ownership and their economic competitiveness
   c) Compare FCEVs benefits vis-à-vis of other vehicle powertrain (e.g., conventional, xEVs)

2. Analyze cost benefit of incremental improvements in fuel cell and storage technologies
   a) Quantify the incremental monetary savings for consumers from investing in more efficient FCEVs.
   b) Define the maximum acceptable cost increase for specific fuel cell system efficiency improvements

Approach

Impact of Fuel Cell System Peak Efficiency on Fuel Consumption and Cost



QUANTIFY THE TECHNICAL AND ECONOMIC IMPACT OF TECHNOLOGIES FUNDED BY FCTO

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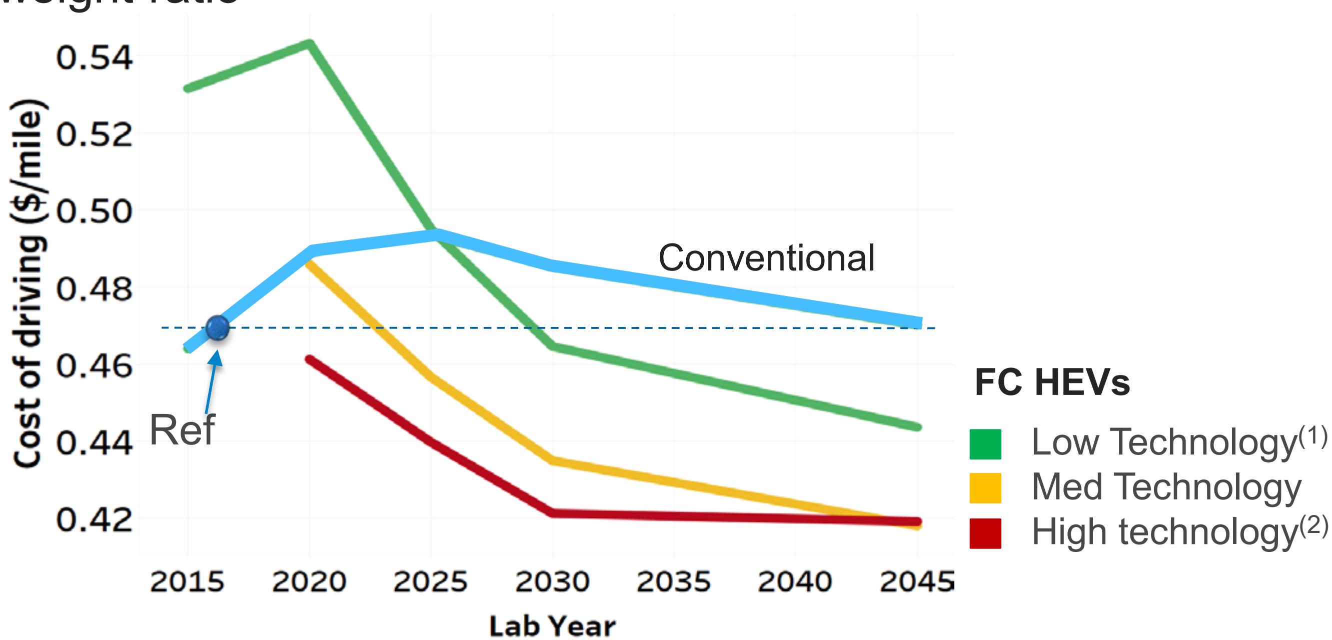
Technical Accomplishment: Published Baseline Scenario (BaSce) Report & Cost Benefit Analysis

- A report on "Fuel Cell Powered Vehicles: Technology Progress Impact on Technical and Economic Feasibility" was released in May 2017
  - An updated version of the fuel cell technology review is included as part of the 2018 BaSce Report including the impact of
    - Fuel cell efficiency
    - Fuel cell cost
    - H_2 storage cost
    - H_2 storage weight ratio



https://www.autonomie.net/publications/fuel_cell_powered_vehicles_analysis_report.html

(1) Business as usual (2) FCTO and VTO targets

Main Study Assumptions

Assumptions provided for 2010, 2015, 2025 and 2045 Lab Years
Lab Year = Model Year – 5 Years

- Fuel-cell system assumptions

Lab Year	2010	2015	2025			2045		
Technology Case	Low	Low	Low	Medium	High	Low	Medium	High
FC System – Specific Power (*W/kg*)	650	650	659	665	710	670	760	870
Peak Fuel Cell System Efficiency at 25% Rated (%)	60	60	64	64	64	68	69	70
Conventional Engine Efficiency (Gasoline) (%)	36	36	38	40	43	43	47	50
Power-split HEV Engine Efficiency (Gasoline) (%)	39	40	40	43	46	42	47	52

- H_2 storage weight assumptions (weight = A + B X fuel mass)

Lab Year	2010	2015	2025			2045		
Technology Case	Low[a]	Low	Low	Medium	High	Low	Medium	High
A	28	28	24	17	14	14	10	9
B	21	21	21	20	20	20	15	12

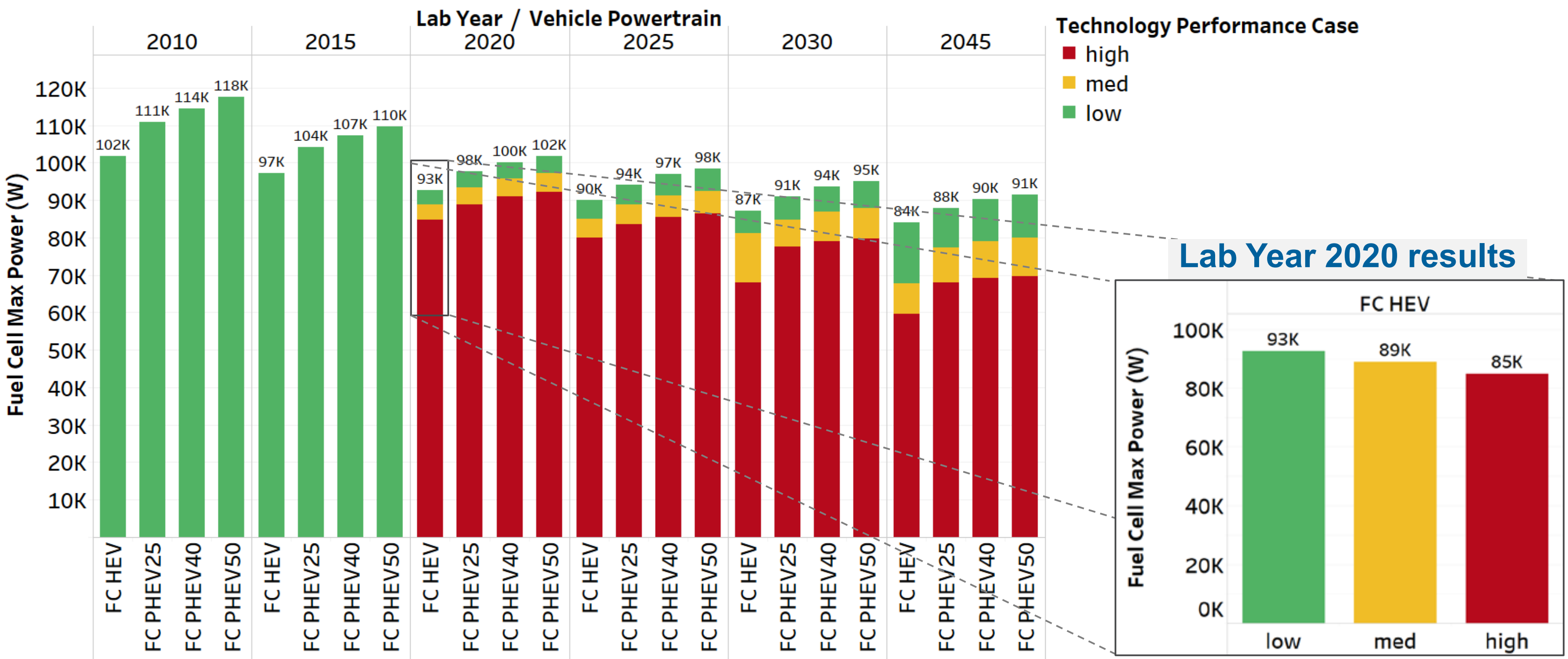
- Fuel-cell cost assumptions (cost = A + [B + (C X Platinum price)] X FC power)

Lab Year	2015	2025			2030			2045		
Technology Case	Low	Low	Medium	High	Low	Medium	High	Low	Medium	High
A	1516	1785	1414	1312	1500	1200	1140	1300	1080	1060
B	19.676	17.24	13.73	12.78	16	12.2	11.6	15	12	11.6
C	0.009579	0.00799	0.00480	0.00348	0.007	0.0045	0.00346	0.0066	0.0044	0.00346

- H_2 storage cost assumptions (cost = A + B X fuel mass)

Lab Year	2015	2025			2030			2045		
Technology Case	Low	Low	Medium	High	Low	Medium	High	Low	Medium	High
A	983	863	649	559	649	559	476	559	420	326
B	428	397	384	358	384	358	304	358	268	215
$/kWh	14.8	16.5	15.0	13.8	15.0	13.8	11.7	13.8	10.3	8.3

Fuel Cell Power Reduced up to 42% As a Result of Vehicle Technology Improvements

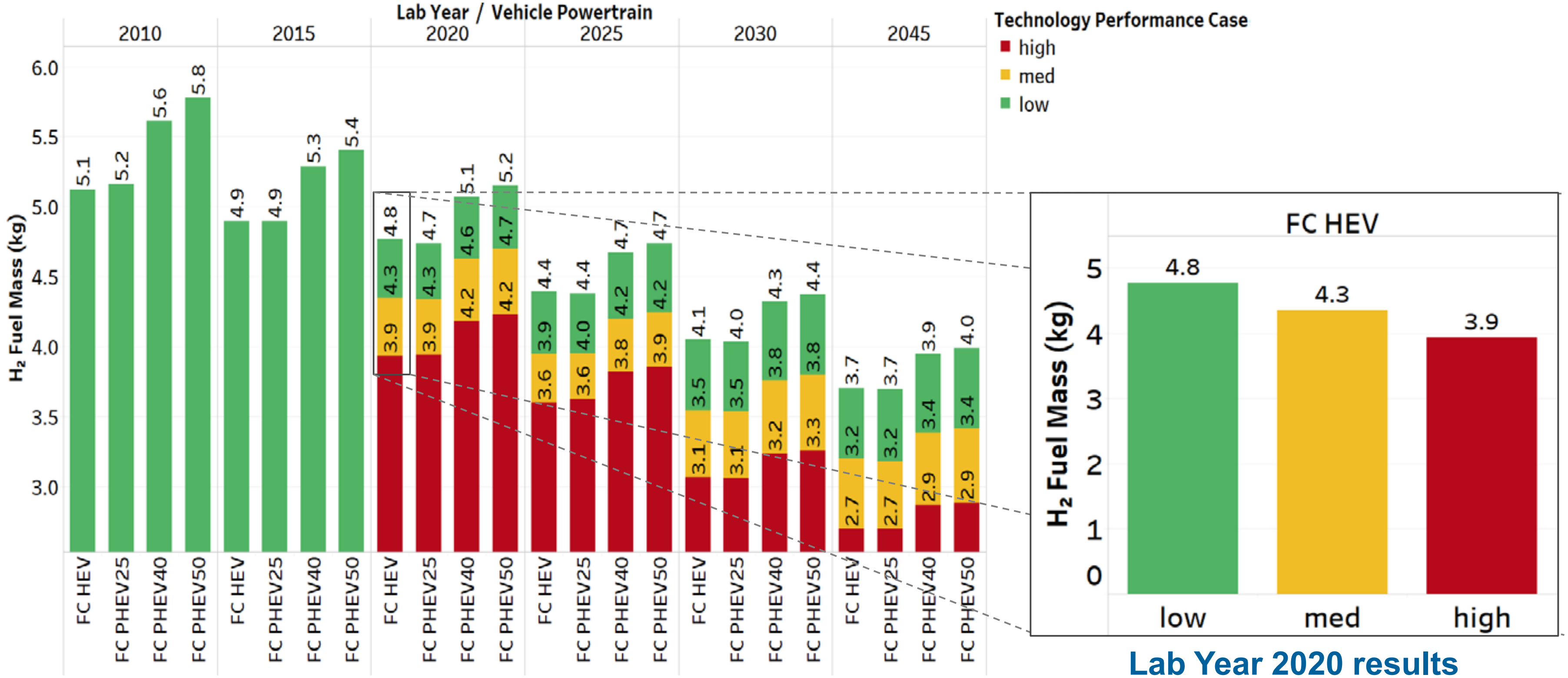


The reduction in power requirements that occurs from lab years 2010 to 2045 ranges from

- 17% to 42% for FC HEVs,
- 21% to 39% for FC PHEV25 AERs,
- 21% to 40% for FC PHEV40 AERs,
- 22% to 41% for FC PHEV50 AERs.

Results shown for midsize sedan

H_2 Storage Requirements Reduced up to 50% Thanks to Vehicle Technology Improvements



Lab Year 2020 results

The reduction in amount of H_2 used that occurs from lab years 2010 to 2045 ranges from

- 28% to 47% for FC HEVs,
- 28% to 48% for FC PHEV25 AERs,
- 30% to 49% for FC PHEV40 AERs,
- 31% to 50% for FC PHEV50 AERs.

Results shown for midsize sedan

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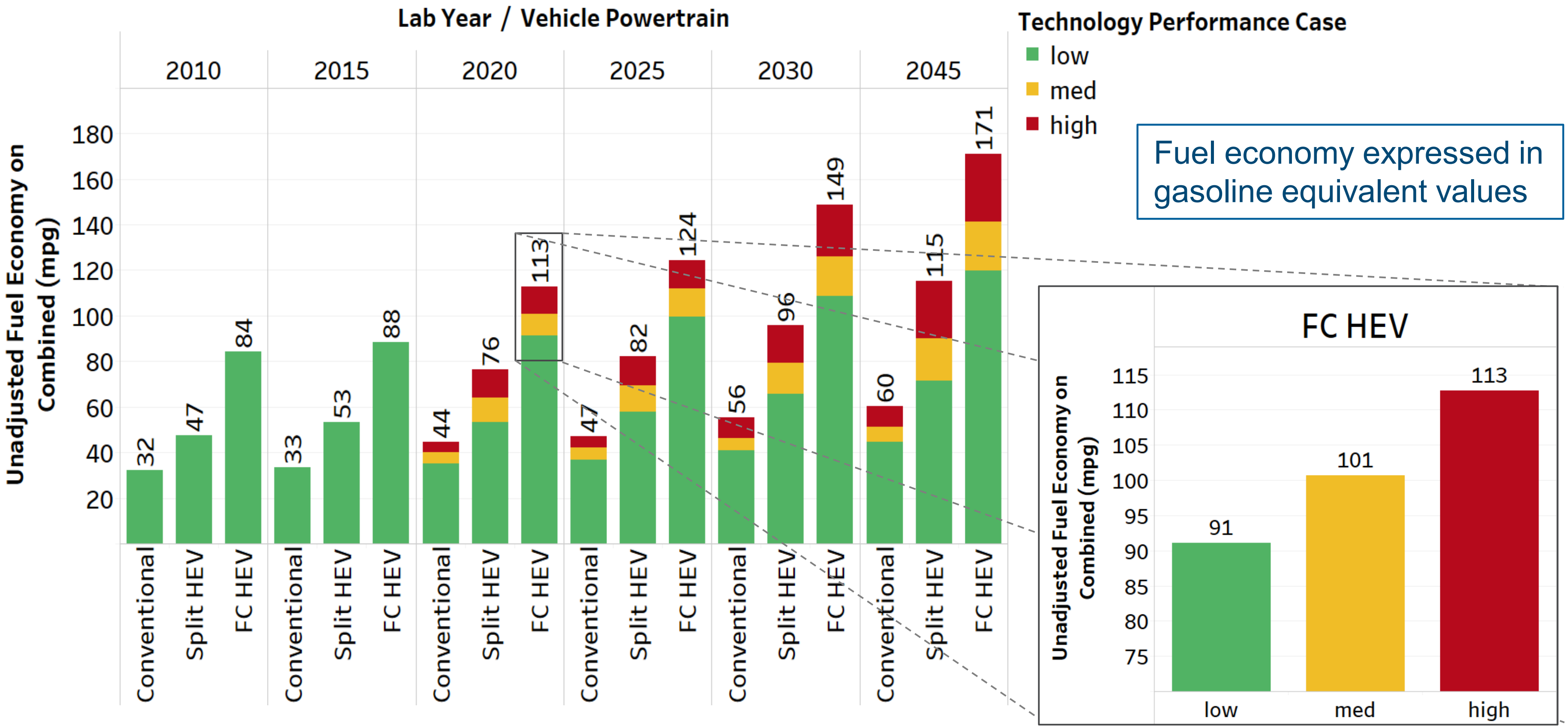
Fuel Cell Vehicles Maintain a Significant Fuel Efficiency Advantages Compared to Conventional and HEVs



Lab Year 2020 results

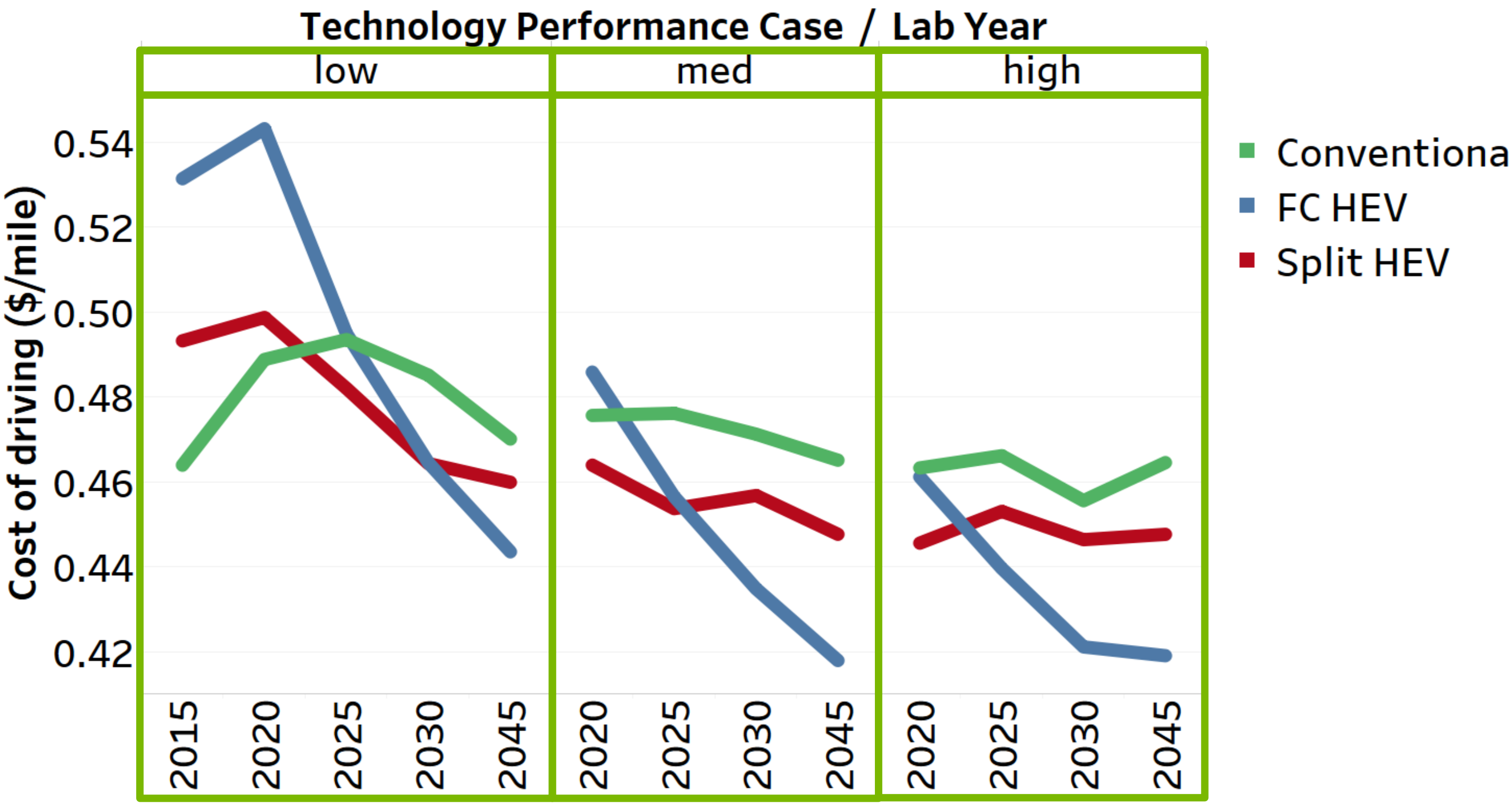
By 2045 Lab Year, FCEV consumes

- 63% to 65% less fuel compared to gasoline conventional
- 33% to 40% less fuel when compared to gasoline Split-HEV.

Results shown for midsize sedan

FCEVs Could Reach Life Cycle Cost Parity with Conventional Vehicles by 2020

Lifecycle cost ($/mile) of FC HEV compared to conventional and hybrid vehicles

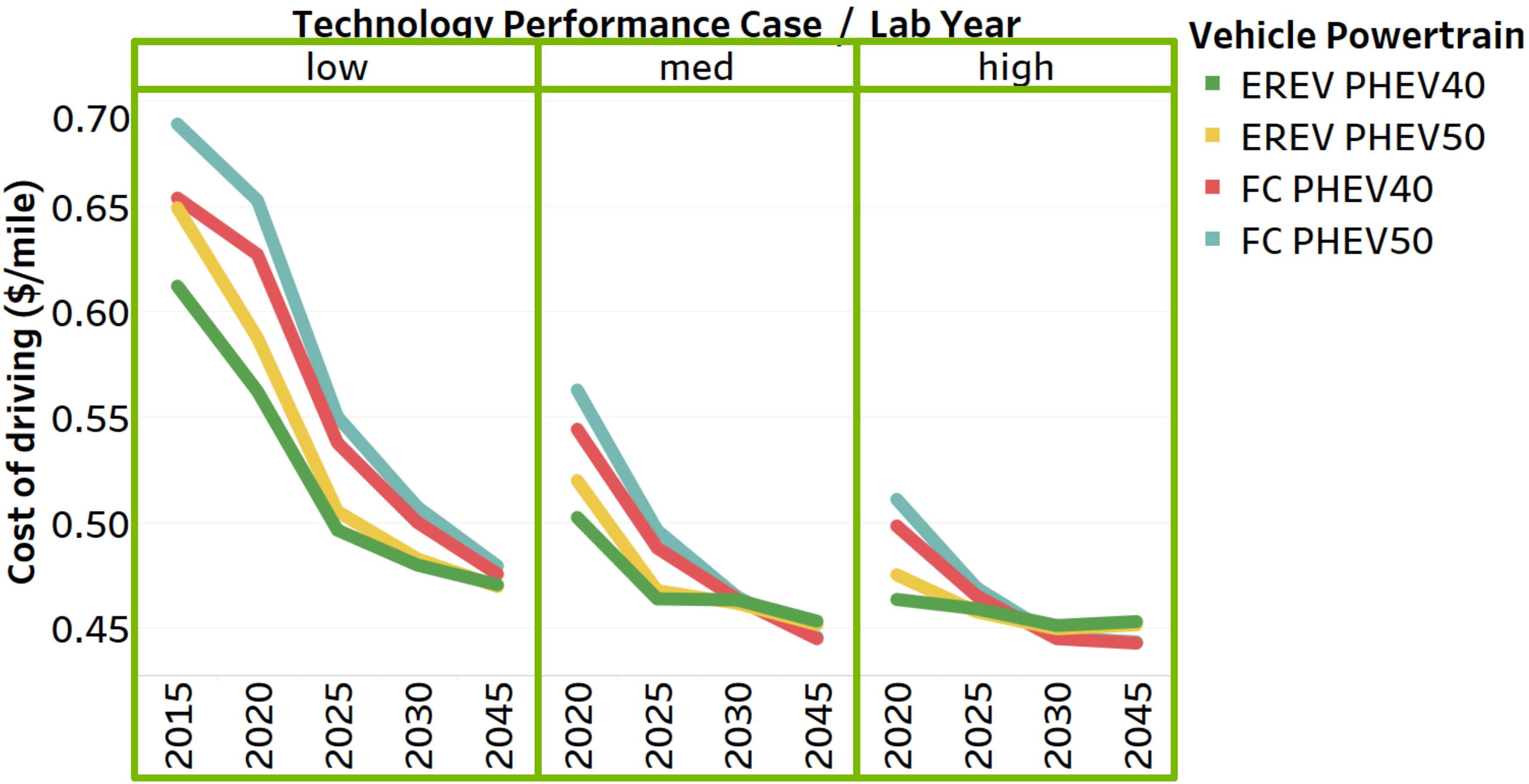


Results shown for midsize sedan

Even under low technology improvement case, cost parity between FCEVs and conventional vehicles is expected to occur by 2025

FCEVs Could Reach Life Cycle Cost Parity with PHEVs by 2025

Lifecycle cost ($/mile) of FC PHEV40/50 compared to gasoline EREV PHEV 40/50



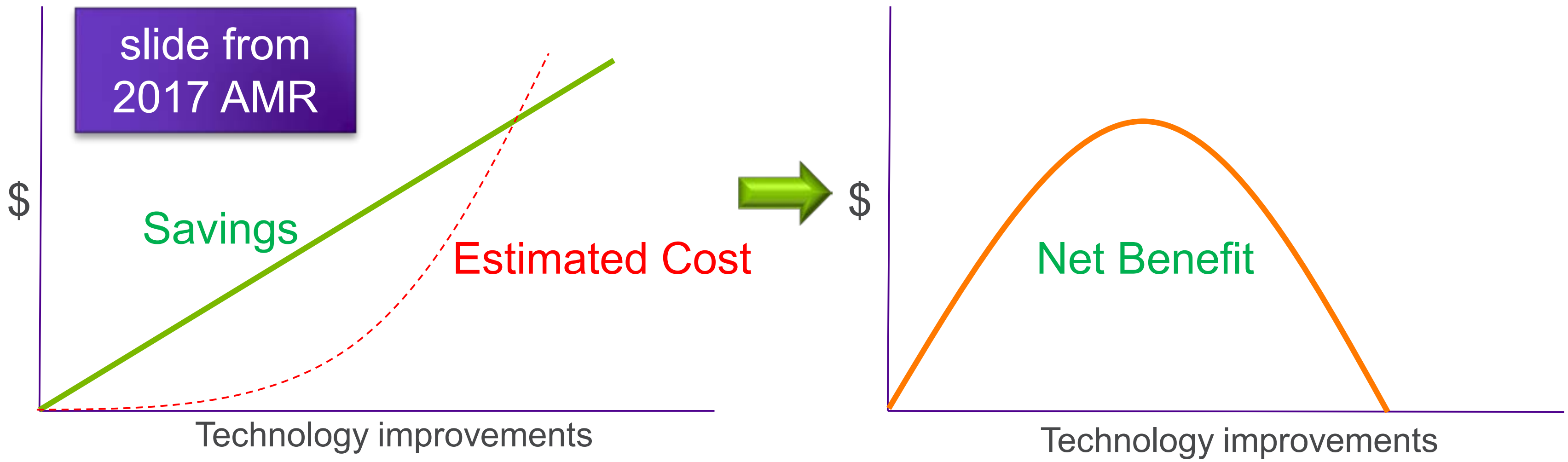
Results shown for midsize sedan

COST BENEFIT ANALYSIS OF INCREMENTAL IMPROVEMENTS IN FUEL CELL AND STORAGE TECHNOLOGIES

Approach: Cost & Benefits of Improving Fuel Cell System & Storage Technology

Quantify the Marginal Cost & Benefits for a Midsize Sedan

- 2010 Lab Year FCEV technology is considered as the baseline.
  - Improving efficiency or reducing the weight of the tank will result in fuel savings to the consumer.
  - If fuel savings outweigh the cost incurred in implementing a new technology, the change is economically viable.
- The maximum savings that can be recovered from improved fuel economy serves as a cost target for the incremental cost increase in technology

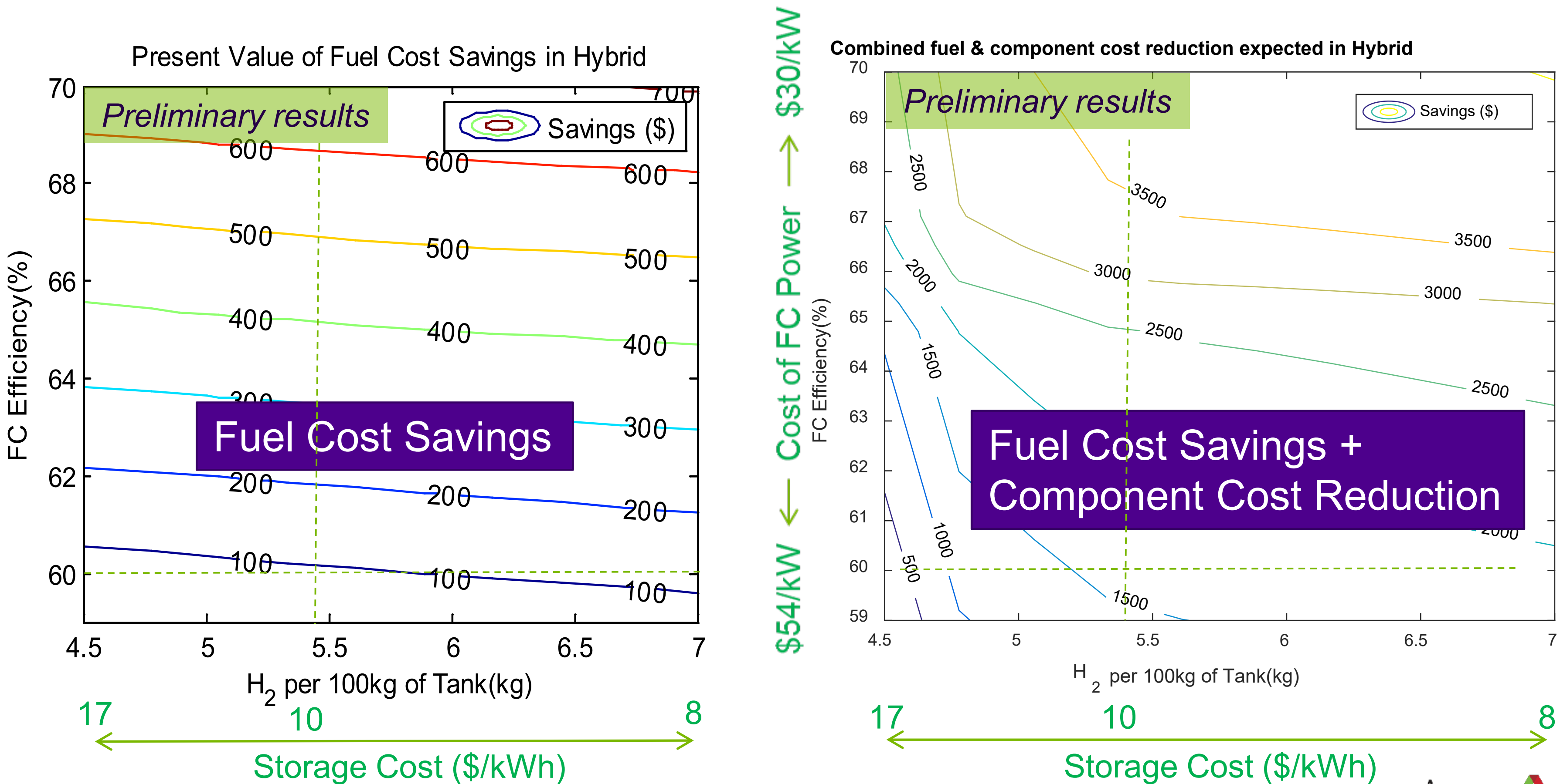


'Savings' was quantified last year. Cost estimate and net benefit are determined in this work

FY17 AMR: Technical Accomplishment

Quantified Fuel Cell & Storage Improvements Savings (up to $4000 for FCEV Consumer compared to present day FCEV)

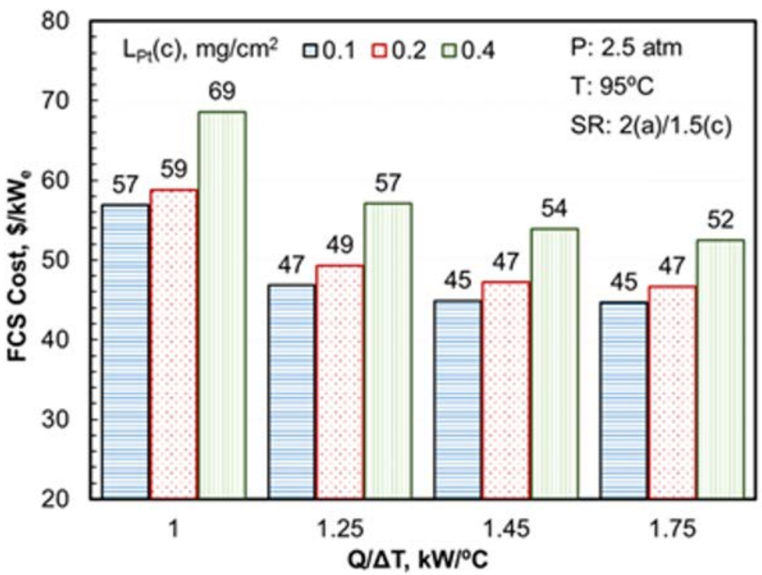
- Over a 5 year ownership period
- 7% discount rate, VMT : 14k miles/year, Cost of H_2 : $4/gge



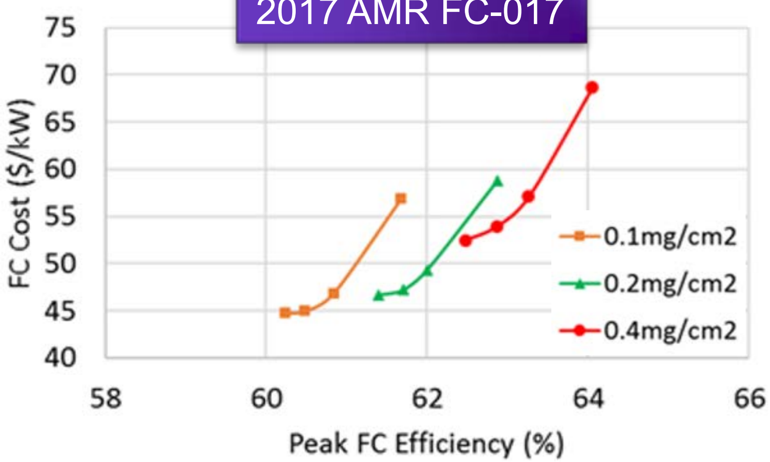
Results shown for midsize sedan

Design Choices Considered: Varying Platinum Loading and Thermal Characteristics

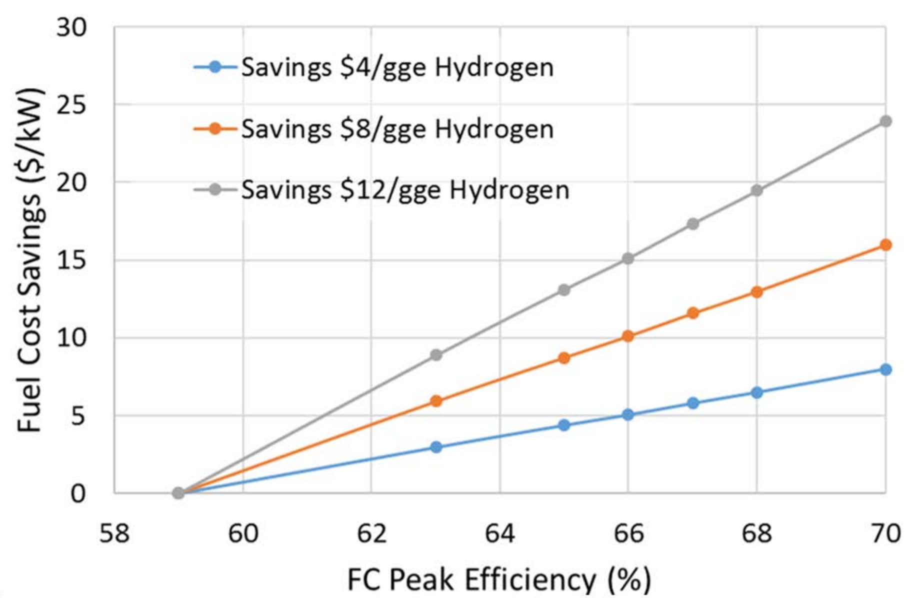
Achieving higher efficiency at an incremental increase in cost



2017 AMR FC-017

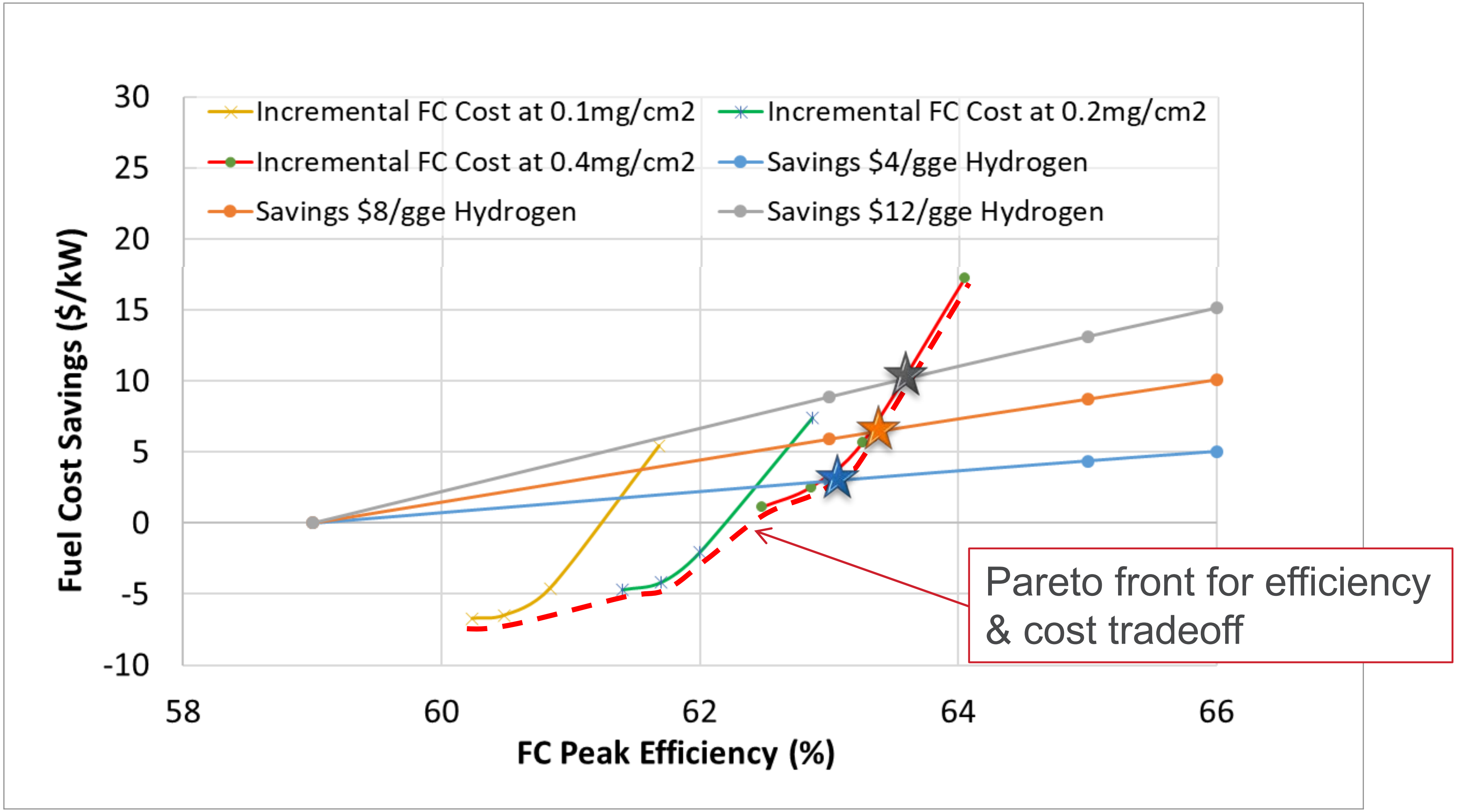


- Based on H_2 cost the savings obtained from higher FC efficiency varies.
- The savings is converted to $/kW units to compare against the cost targets for the FC system



Technical Accomplishment: Acceptable Incremental Cost for a 64% Efficient Fuel Cell Stack Ranges from 4 to 11 $/kW

Cost of H_2 affects the economic viability of FC efficiency improvements



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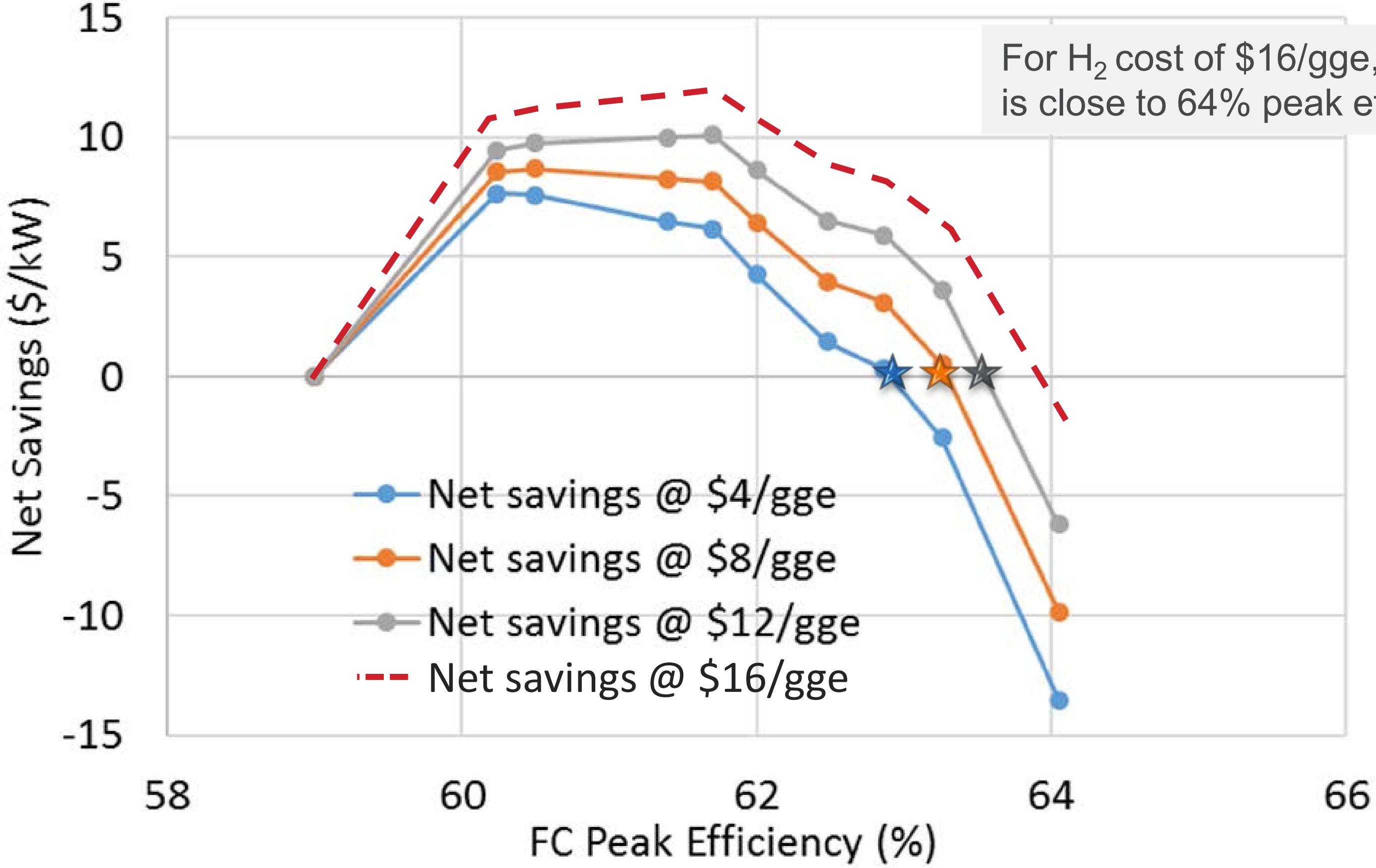
Results shown for midsize sedan

Technical Accomplishment: H2 Cost and Benefits of Higher System Efficiency are Negatively Correlated

Most Benefits Occur for Fuel Cell Systems Designed for 60 to 62% Peak Efficiency



For H_2 cost of $16/gge, breakeven is close to 64% peak efficiency.

Results shown for midsize sedan

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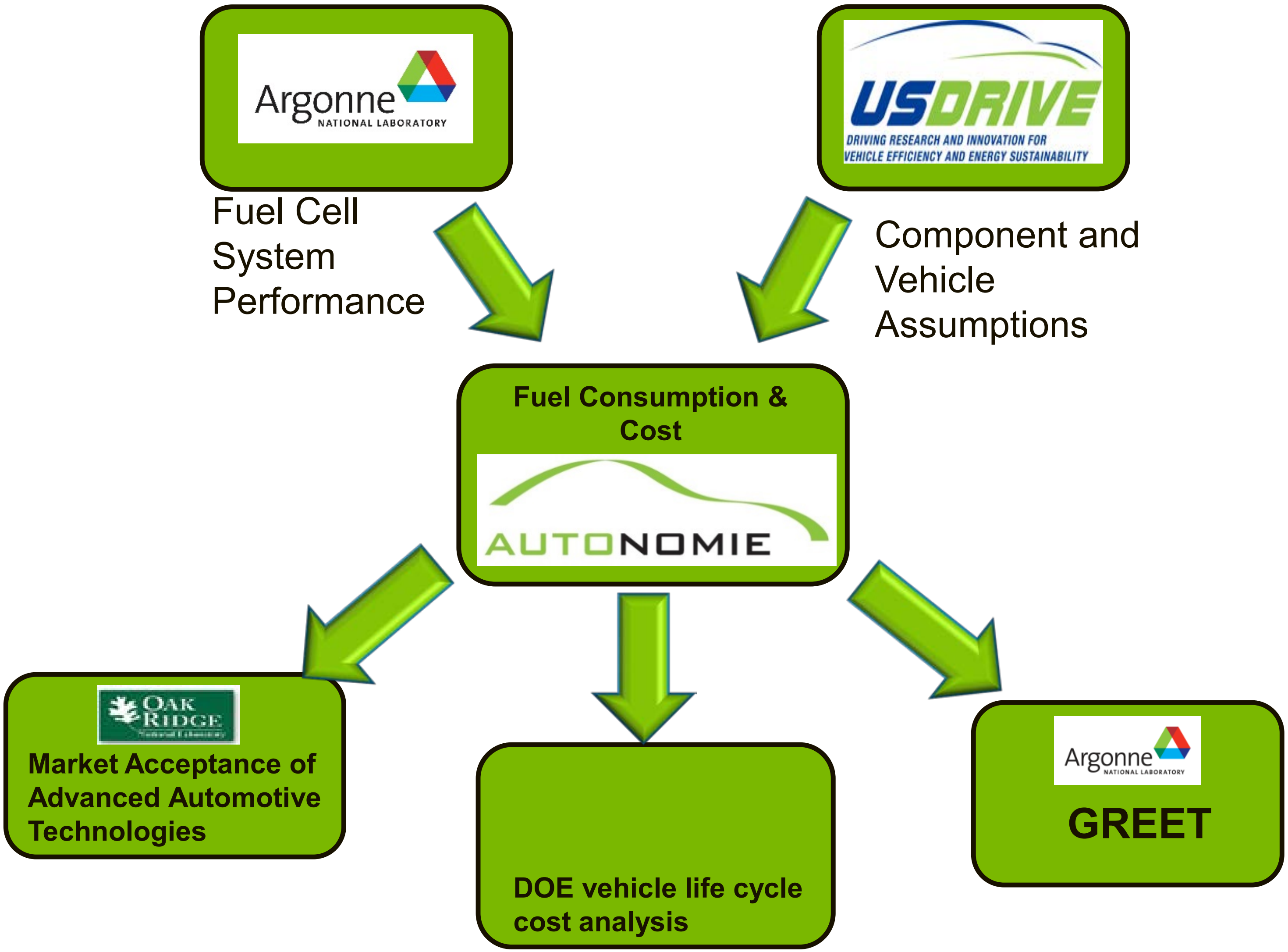
Collaboration and Coordination with Other Institutions



Response to Reviewer Comments

Reviews were very encouraging and positive. There were comments/suggestions provided by reviewers to improve the study.

- Analysis with just one H_2 cost assumption ($4/gge) was deemed insufficient.
  - *Included higher costs for short term analysis*
- Analysis should be contextualized with other powertrain architectures
  - *Included Conv, HEV, and PHEVs in $/mile comparisons*
- One reviewer encouraged greater interaction with industry partners
  - *We are pursuing this. We work closely with companies that do some of the prototype development projects for FCTO.*
  - *We are also updating our models based on learnings from testing vehicles such as the Toyota Mirai.*

Next Steps – Expand Analysis for Medium and Heavy Duty Vehicles

- 13 class vocation combinations are already built under FCTO & VTO funded projects *(2016 AMR:TV032 & 2017 AMR: VAN023)*
- Transit buses were added in FY18 (VTO funded)
- Rule based sizing process is developed for
  - Fuel cell powered hybrid (FCHEVs) vehicles &
  - Fuel cell powered range extender (FCREx) vehicles.
- Optimization based sizing to find the balance between the two sizing approaches will be completed in FY18. *(2018 AMR: TV150)*

Any proposed future work is subject to change based on funding levels

Summary

- Quantified FCTO benefits for light duty vehicles
  - Advanced vehicle technologies will allow a reduction of up to 41% in fuel cell power and up to 50% in H2 storage
  - Fuel cell vehicles could reach life cycle cost ($/mile) parity with conventional vehicles by 2020 and with PHEVs by 2025

- Quantified maximum incremental cost for additional fuel cell system and H2 storage improvements
  - Based on current assumption, fuel cell system peak efficiency improvement beyond 63% - 64% will not be economically viable for the consumer
  - A maximum incremental cost of $4 to $11/kW is acceptable for a 64% peak efficiency compared to a 59% system

- Component cost reduction remains the main driving factor for FCEVs to become economically feasible.

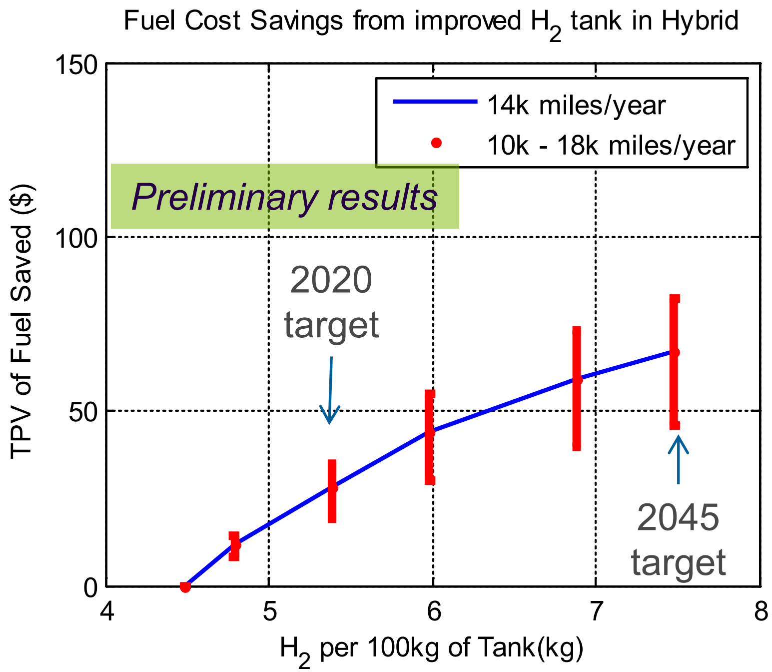
Backup Slides

Improvements in H_2 storage density does not have a big impact on fuel savings

Storage cost reduction has a direct impact.

60% improvement in H_2 storage capacity of tanks saves less than $100 in fuel costs over a 5 year ownership period.

- Improved tanks results in relatively small fuel economy improvements.
  - TPV of fuel savings is ~$60 for Hybrids and ~$100 for PHEV20.
  - A direct cost reduction in tank could have a big impact.



*BaSce 2015 technology is considered as the baseline for all cost saving estimates

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