

Project ID # SA044 -



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



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2017 DOE Hydrogen Program and Vehicle Technologies
Annual Merit Review

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Project Overview -

Timeline	Barriers
<ul style="list-style-type: none">• Project start date : Sep 2016• Project end date : Aug 2017• Percent complete : 75%	<ul style="list-style-type: none">• Lack of Fuel Cell Electric Vehicle and Fuel Cell Bus Performance and Durability Data (A)• Hydrogen Storage (C) <p>http://energy.gov/sites/prod/files/2015/06/f23/fcto_myRDD_tech_valid.pdf</p>
Budget	Partners
<ul style="list-style-type: none">• FY17 Funding : \$120• Percent spent : 75%	<ul style="list-style-type: none">• Argonne Fuel Cell Team

Overview / Relevance

What is the Maximum Incremental Cost for Specific Efficiency Improvements of Fuel Cell Technologies? -

- Present technology levels
 - Fuel cells : 59% efficiency
 - H₂Tank : 4.5kg of H₂ per 100kg of storage mass.
- Expected improvements will save fuel for the consumer.
 - They may also entail a higher initial cost.

Objectives

1. Quantify the fuel cost savings for a consumer who adopts a better technology.
2. Quantify the overall savings if DOE cost targets are met.
3. Compare the savings against cost estimates from experts

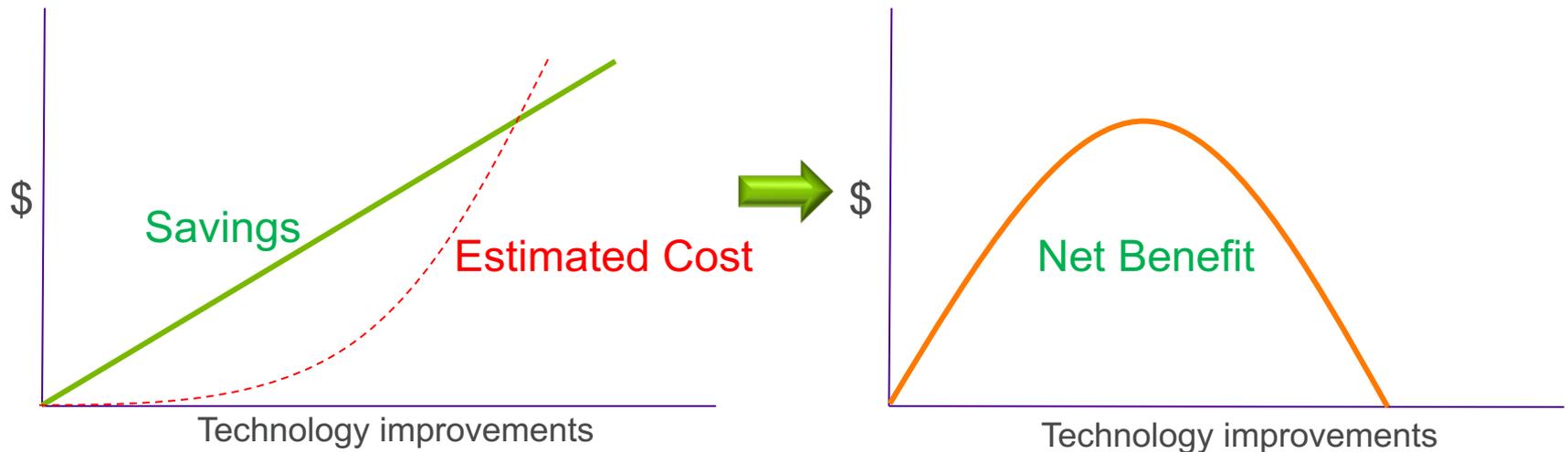
Parameter	Units	Ref	Expected Future Improvements					
FC System-Specific Power	W/kg	659	659	670	680	710	740	870
Peak FC Efficiency at 25% Rated Power	%	59	63	65	66	67	68	70

Parameter	Units	Ref	Expected Future Improvements					
System Capacity	Useable kg H ₂ /kg of tank	0.045	0.045	0.048	0.054	0.060	0.069	0.075
H ₂ Used in Tank	%	96	96	96	96	97	97	97

Objectives

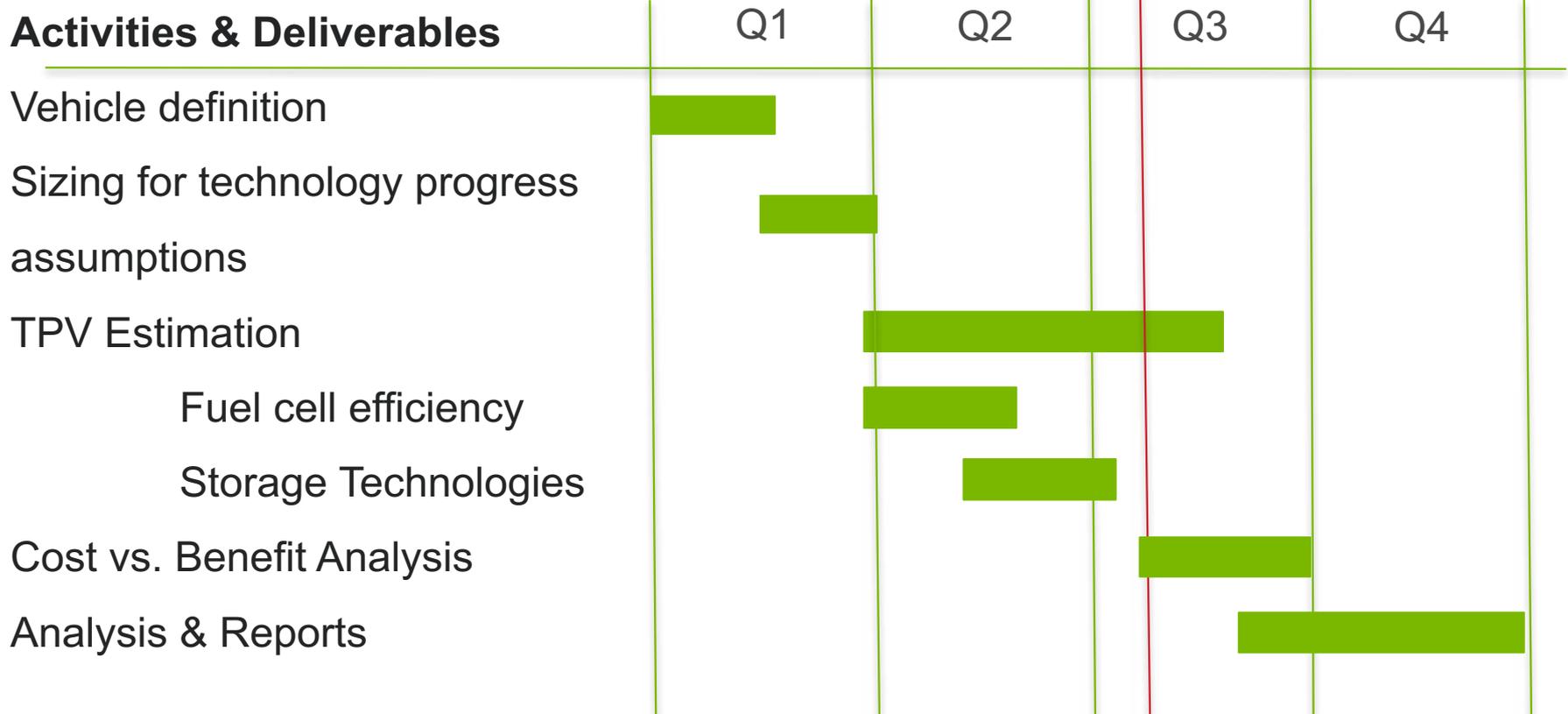
Quantify the Marginal Cost & Benefits from Fuel Cell System & Storage Technology Improvements

- Present day 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



Milestones -

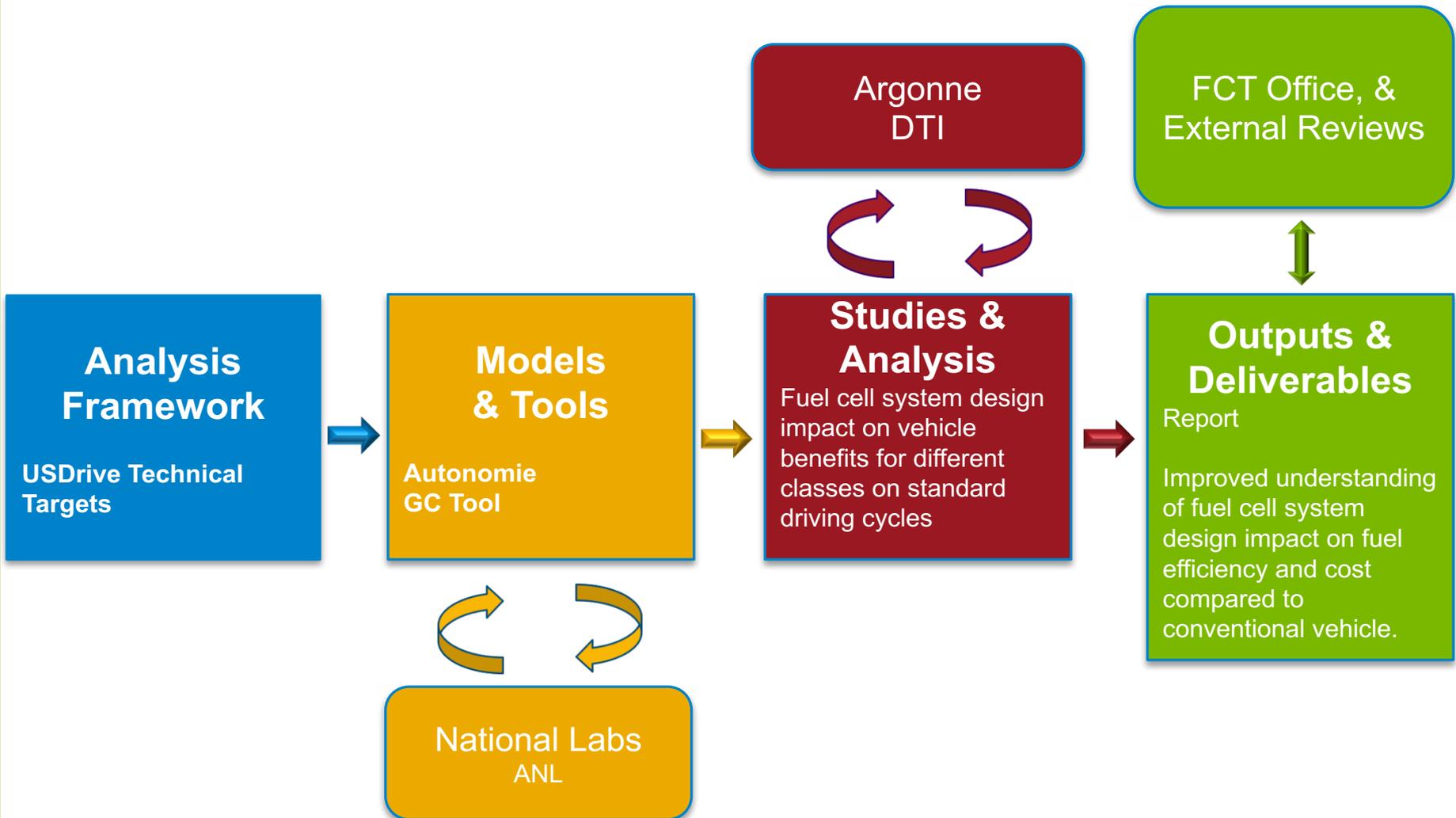
Activities & Deliverables



- Preliminary results are available now.
- More analysis and report is due by Sep 2017 -

Approach

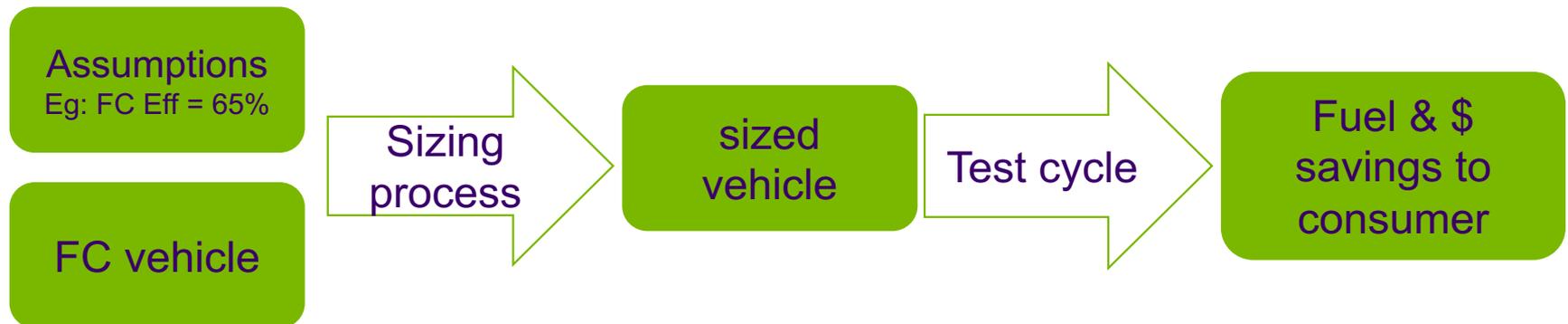
Impact of Fuel Cell System Peak Efficiency on Fuel Consumption and Cost



Approach: Powertrain Sizing Process Ensures Fair Comparison Across Technologies

All vehicles are sized to meet similar performances

- Each technology improvement and combinations of technology changes are evaluated.
 - FC system improvements includes efficiency and power density.
 - H₂ systems improvements include weight ratio and increase in usable fraction of stored H₂



Critical Assumptions: Vehicles & Cycles

Powertrain Sizing Logic & Assumptions from FCTO Benefit Analysis (BaSce)

- Reference vehicle models (i.e. FC HEV) leveraged from previous studies
 - FC PHEV-20 is added to show trends related to all electric range (AER) -
- Vehicles are sized for 0-60mph in 9s, capable of 6% grade at 65mph
 - FC provides 70% of the peak power demand to meet the performance requirements, electric hybrid system is used to augment the performance.
- Cycles:
 - HEV : Charge sustaining 2 cycles procedure
 - PHEV : PHEV test procedure (2 cycles and Utility Factor weighting)
- Total Present Value (TPV) of fuel savings is based on following assumptions.
 - Discount rate : 7%
 - Service duration : 5 years
 - Cost of H₂ : \$4/gge (delivered and dispensed)
 - TPV provides present \$ value of the future fuel savings

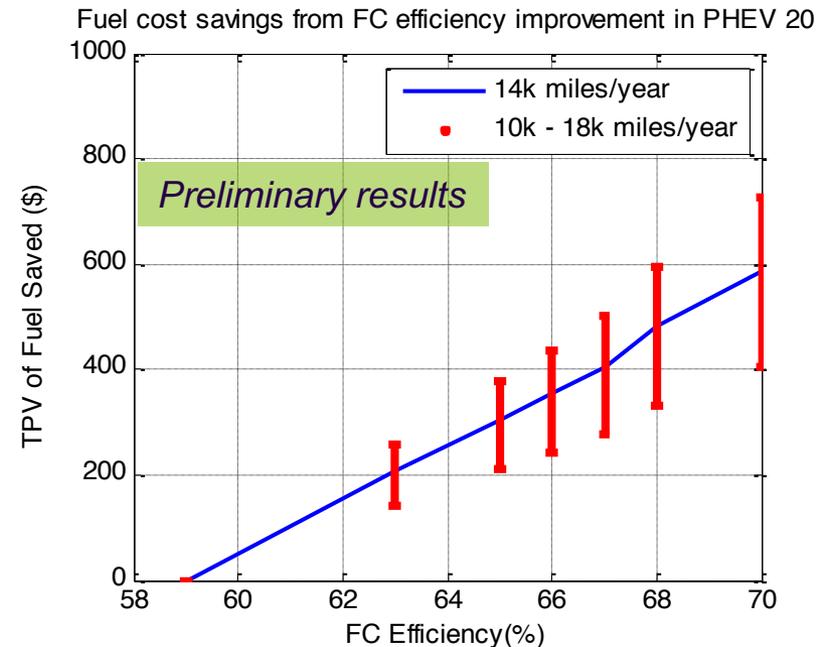
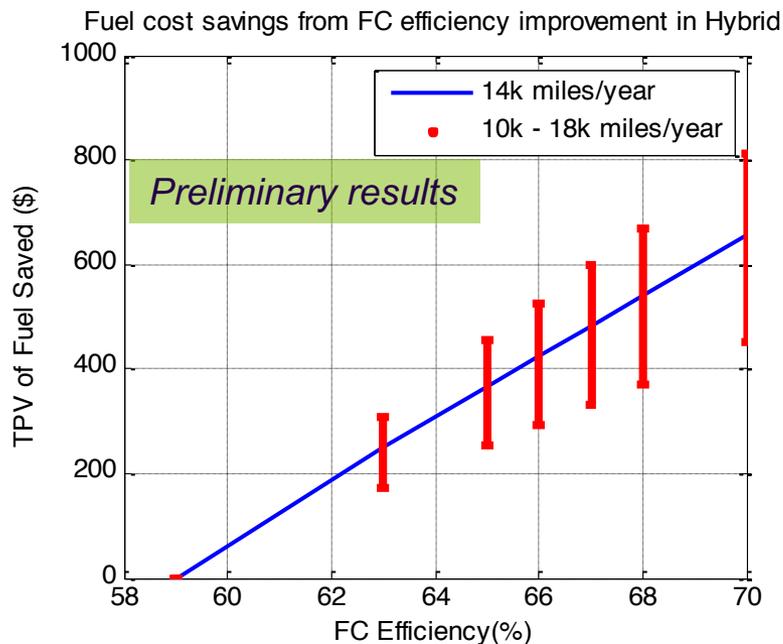
Maximum Incremental Component Cost Resulting from Fuel Savings

Technical Accomplishments

Impact of FC Efficiency Improvements

10% improvement in FC efficiency will save ~\$600 in fuel costs for a FCHEV over 5 years of ownership period

- Savings vary with yearly vehicle miles travelled (VMT).
 - Three cases are considered in this study
 - 10k, 14k & 18k miles/year
- FC HEVs show more savings than PHEVs since they consume more fuel
- FC PHEVs see smaller savings from FC efficiency improvements



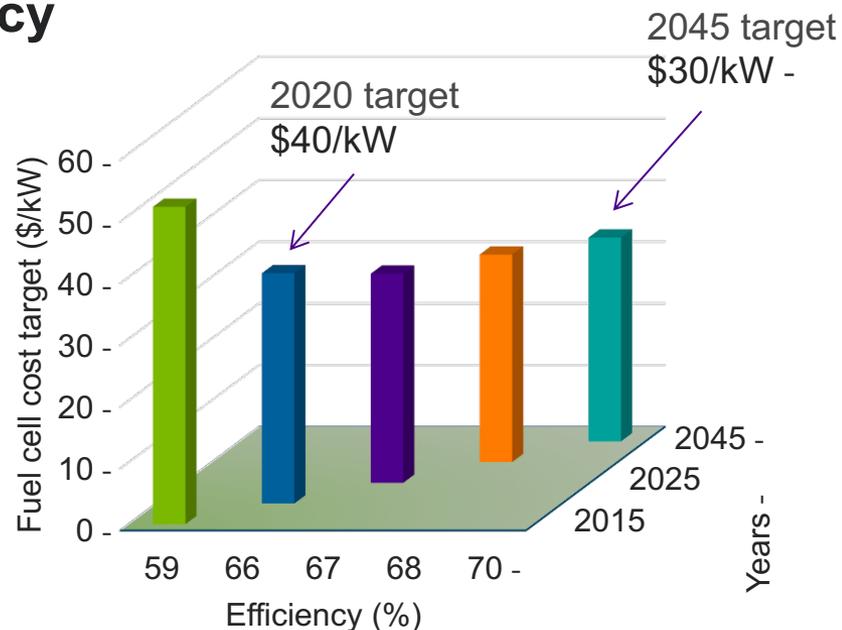
Technical Accomplishments

Allowable Cost for FC Efficiency Improvements

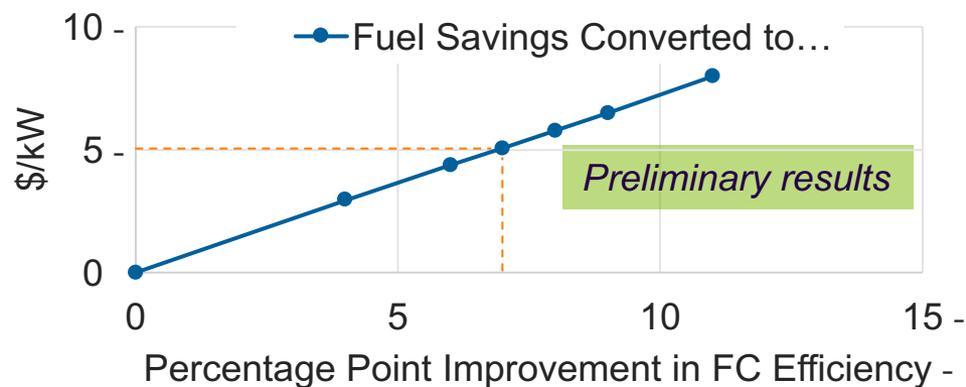
~70c/kW increase in fuel cell cost is justified for every percentage point improvement in fuel cell efficiency

- Fuel cell & storage targets for component cost. -

- 2020 target for fuel cell is \$40/kW & 66% efficiency -
- 2045 target for fuel cell is \$30/kW & 70% efficiency -



- Result: If the efficiency of today's fuel cell can be improved from 59% to 66%
 - Cost increase of up to \$5/kW can be justified because of fuel savings



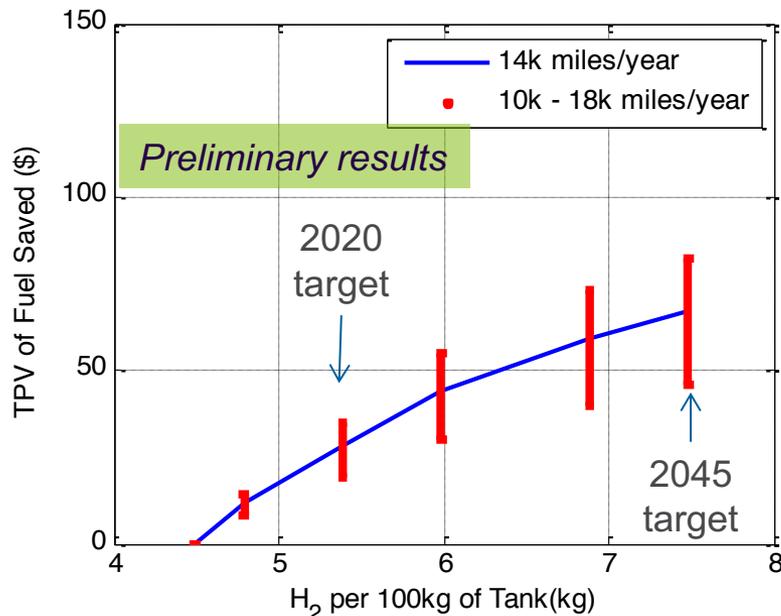
Technical Accomplishments

Impact of H₂ Storage Improvements

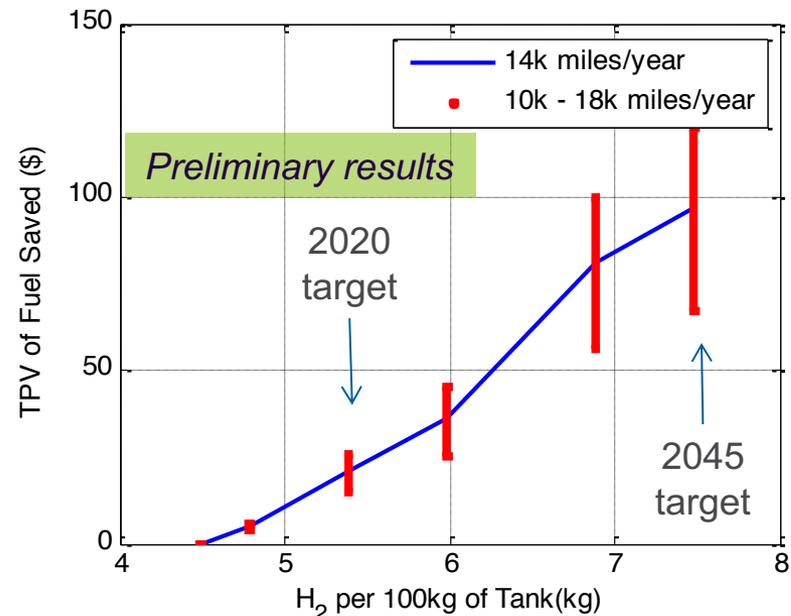
60% improvement in H₂ storage capacity of tanks saves less than \$100 in fuel costs over a 5 year ownership period.

- 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.
- FC HEV is less sensitive to vehicle mass changes, hence see lesser savings -
- FC PHEVs see more compounding of mass reduction, as a lighter vehicle requires lesser battery energy.

Fuel Cost Savings from improved H₂ tank in Hybrid



Fuel Cost Savings from improved H₂ tank in PHEV 20

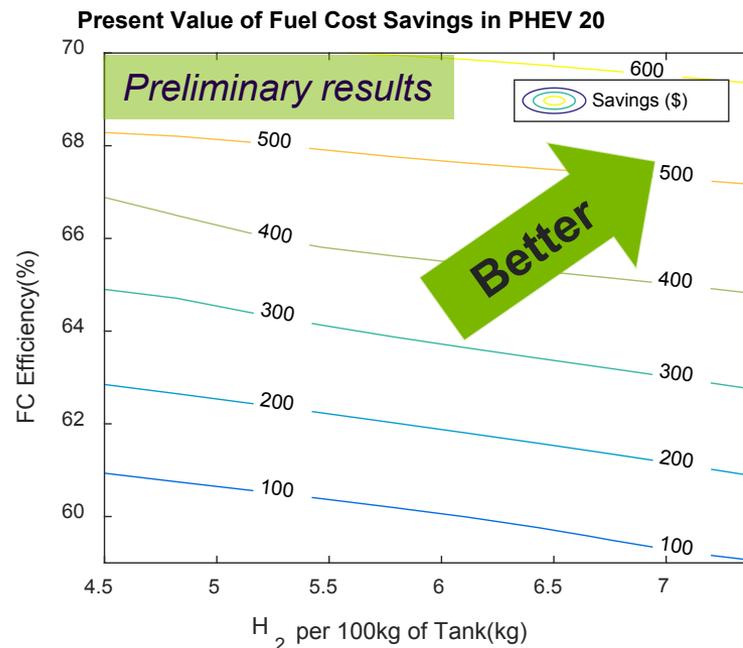
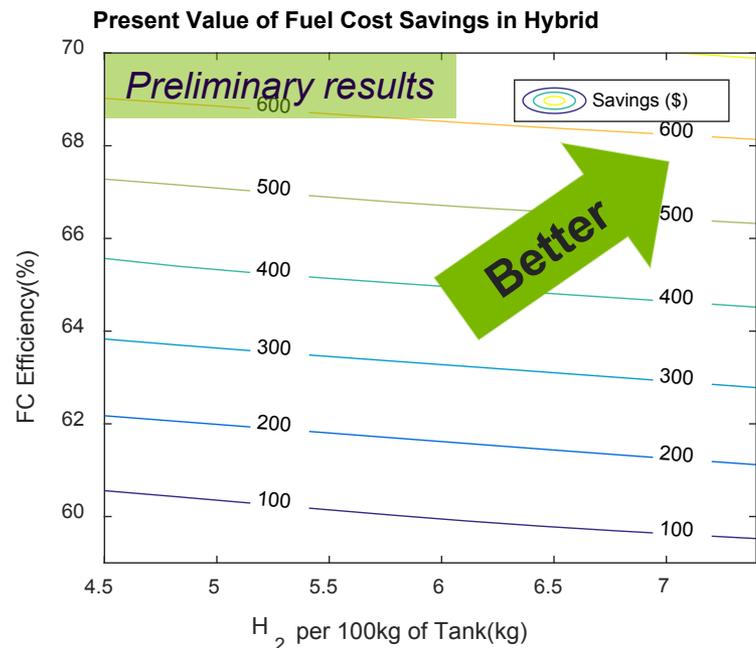


Technical Accomplishments

Fuel Savings (<\$700) Alone Insufficient To Offset Technology Cost Increase

Component Cost Reduction is Needed to Lower the Overall Vehicle Cost.

- Fuel cells are already very efficient compared to conventional vehicles
 - Incremental efficiency improvements provide relatively small savings
- Improving the weight ratio of hydrogen stored in tank, reduces tank weight and helps downsize the powertrain,
 - The benefit observed from those changes are quite small.



Impact of Component Cost Reduction Based On FCTO Targets

Impacts of FCTO Cost Reduction Targets -

Cost targets from FCTO Benefit Analysis

Parameter	Units	2015	2020			2025			2030			2045		
		low	low	med	high									
FC System-Specific Power	W/kg	659	659	670	680	659	665	710	659	680	740	670	760	870
Power Density	W/L	640	640	720	850	640	730	890	640	740	970	690	880	1150
Peak FC Efficiency at 25% Rated Power	%	59	63	65	66	64	66	67	65	67	68	68	69	70
Platinum Price	\$/troy oz	1500	1500			1500			1500			1500		
Cost (\$/kW)	\$/kW	54	48	43	40	44	37	34	40	34	30	39	33	30

The cost is based on high production volumes (500,000 per year).

Parameter	Units	2015	2020			2025			2030			2045		
		low	low	med	high									
System Capacity	Useable kWh/kg	1.5	1.5	1.6	1.8	1.6	1.7	2.0	1.6	1.8	2.3	1.7	2.0	2.5
	Useable kg H2/kg of tank	0.045	0.045	0.048	0.054	0.048	0.051	0.060	0.048	0.054	0.069	0.051	0.060	0.075
Tank Cost	\$/Useable kg H2	576	450	391	335	430	375	310	391	317	274	380	311	267
	\$/kWh	17.2	13.5	11.7	10.0	12.9	11.2	9.3	11.7	9.5	8.2	11.4	9.3	8.0
H2 Used in Tank	%	96	96	96	96	96	96	97	96	96	97	96	97	97

Technical Accomplishments

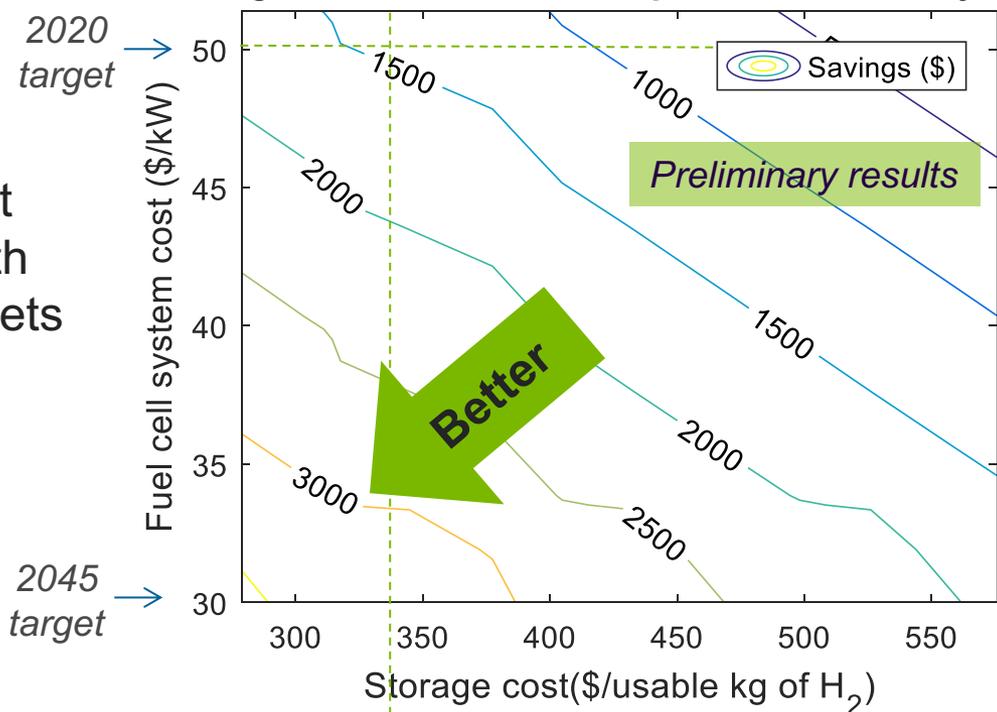
Component Cost Reduction is Needed For Economic Feasibility

Storage system cost savings are as significant as the savings from fuel cell technology improvements

Assumption:

- Fuel cell system and storage cost targets will be achieved along with the technology improvement targets

Targeted reduction in component costs in Hybrid



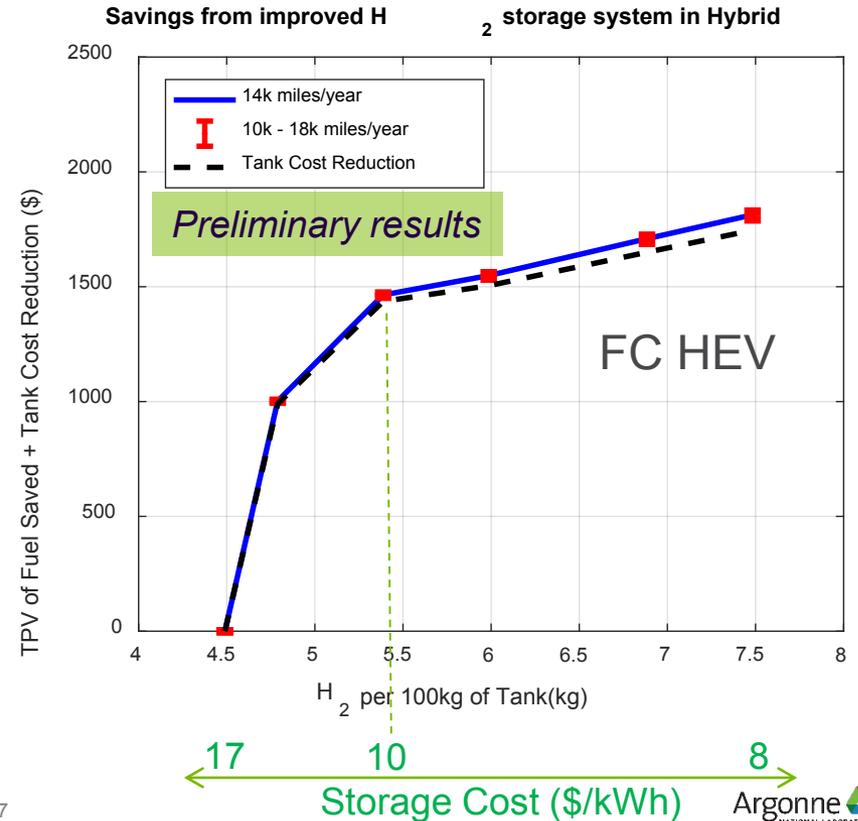
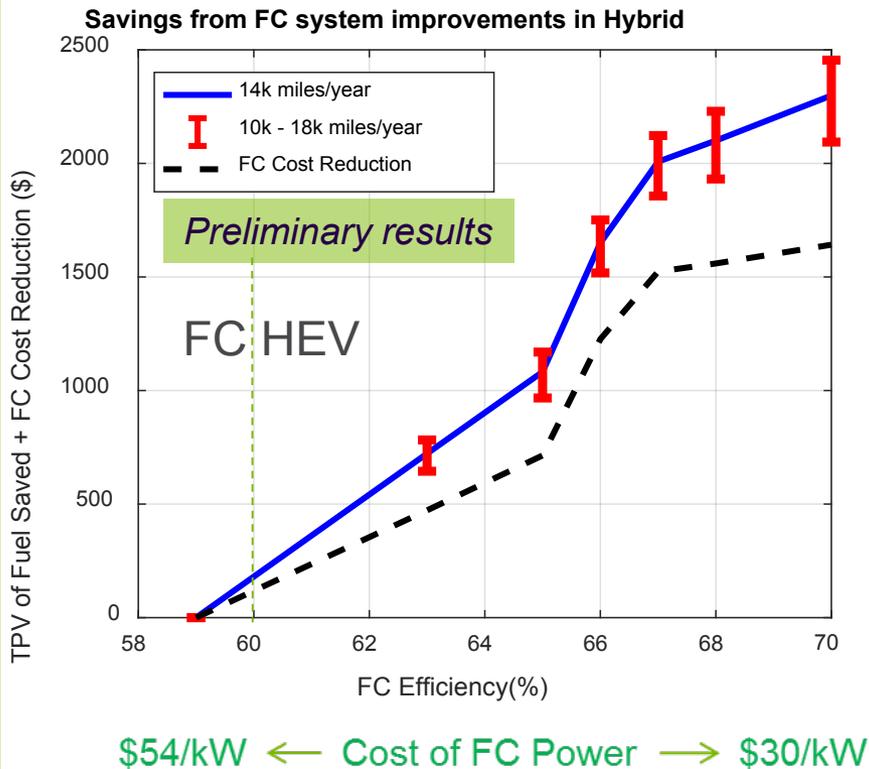
Secondary x-axis is shown to mark the progress expected in component cost.



Technical Accomplishments

Achieving DOE Cost Targets Will Produce Substantial Savings For Consumer

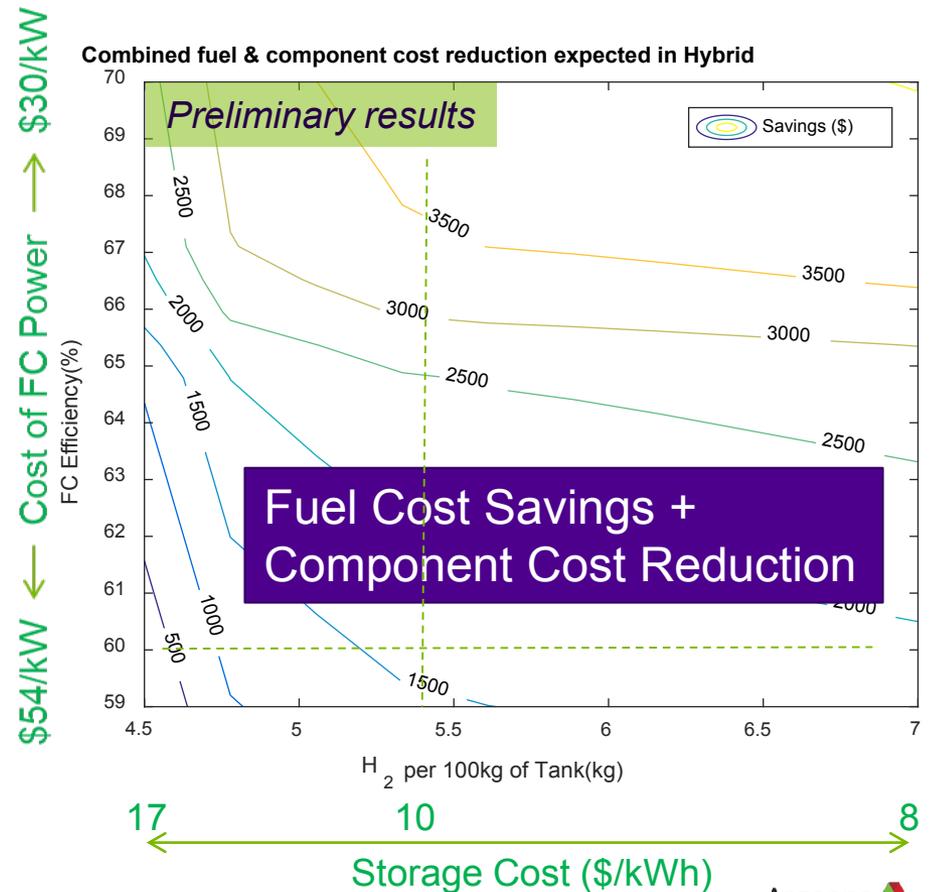
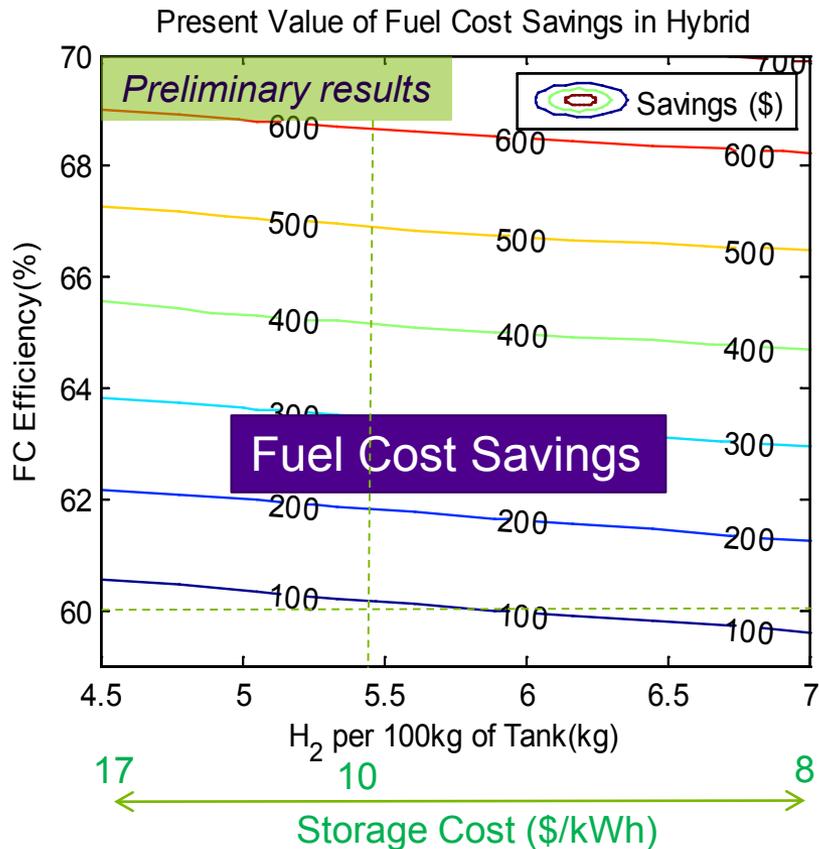
- Fuel savings from weight reduction & efficiency improvements: \$700
- Savings in component manufacturing cost : ~\$3300



Technical Accomplishments

Fuel Cell & Storage Improvements Can Save Over \$4000 for FCEV Consumer, compared to present day FCEV

- Over a 5 year ownership period
- 7% discount rate, VMT : 14k miles/year, Cost of H₂ : \$4/gge



Response to Previous Year Reviewers' Comments on a Related

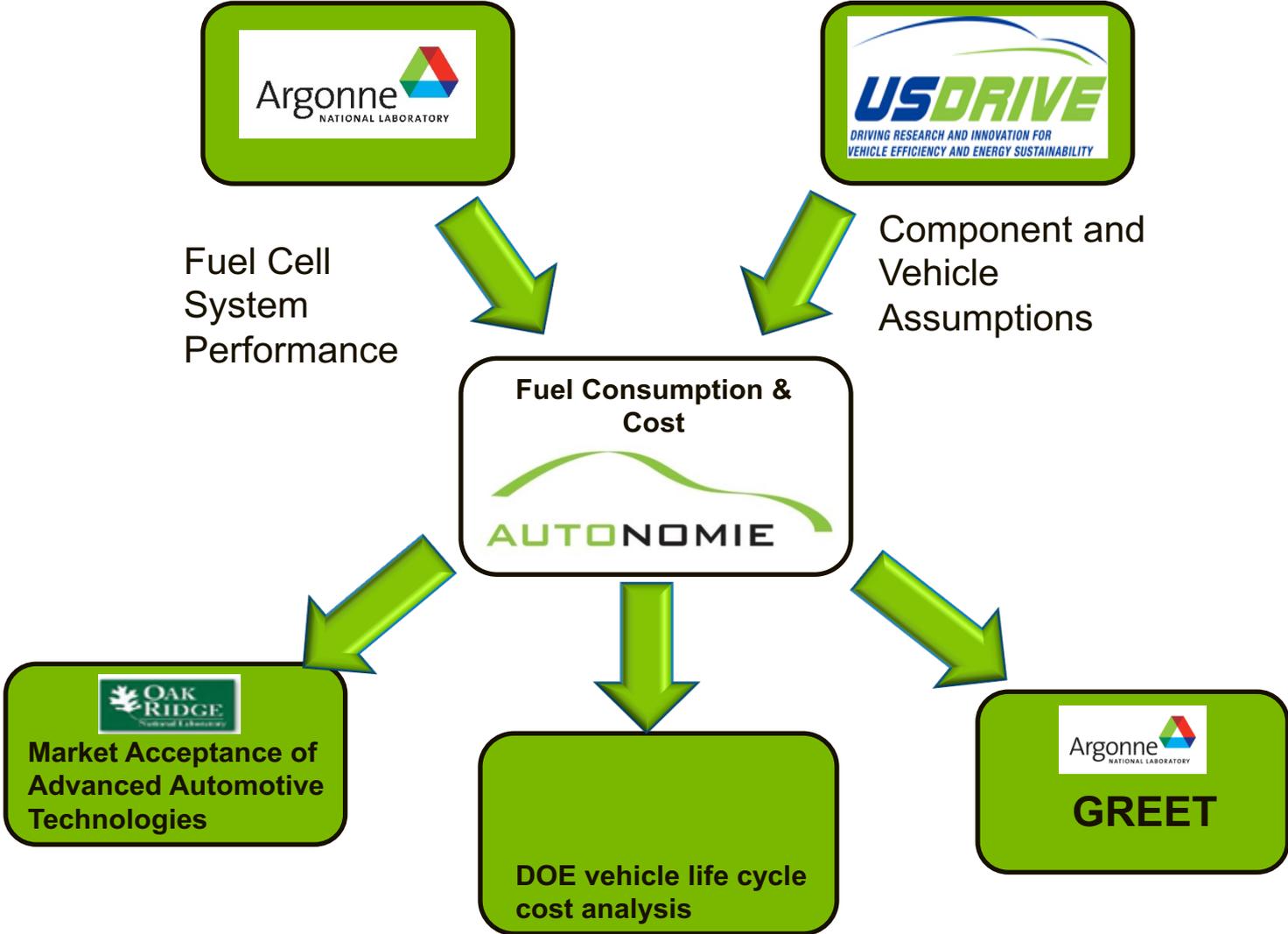
This particular project was not reviewed last year. Analysis of FCTO targets and their impact on feasibility of FCEVs was reviewed.

- The comments were mostly very positive. The suggestions for improvement on the approach and analysis is addressed in this study.

- Comment: The target-based approach is lacking. This project should use actual expected progress, rather than DOE targets.
 - *This study considers actual value of the technology improvements to a consumer.*

- Comment: The same analysis should be performed for business cases with lower volumes of production.
 - *Comparison of FCEVs against Conventional was done last year. This study looks at the cost vs benefit of incremental improvements in fuel cell and storage technologies.*

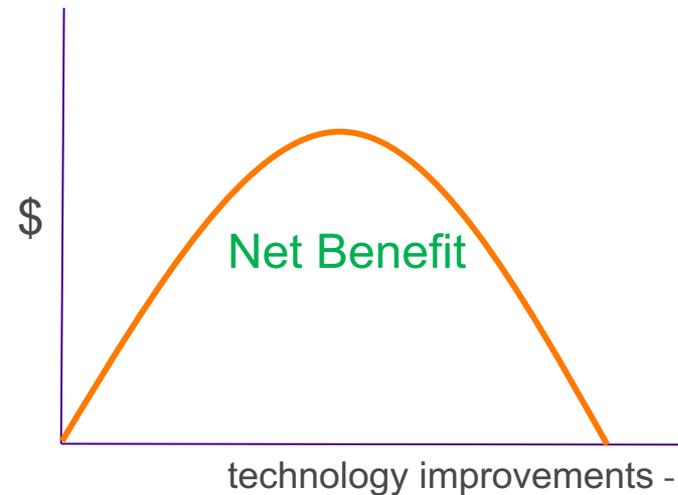
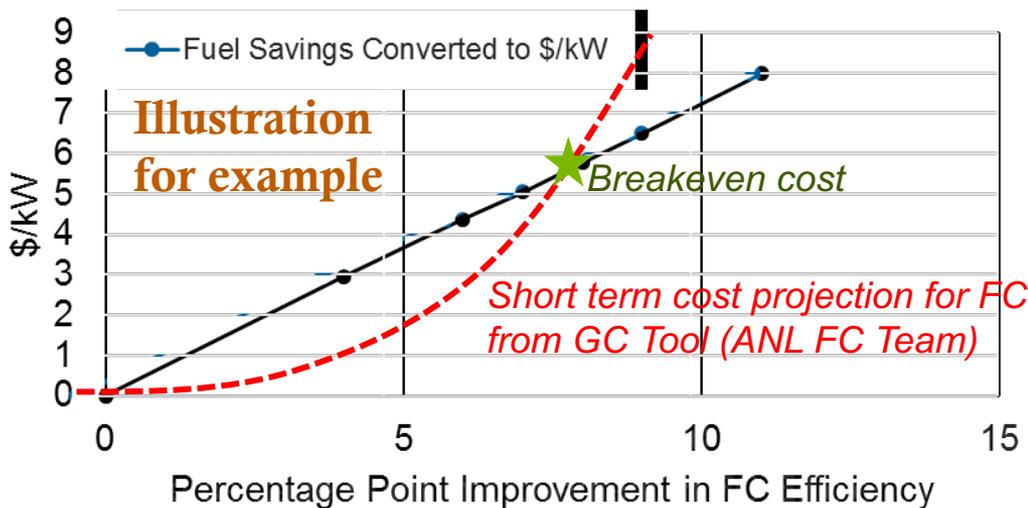
Collaboration and Coordination with Other Institutions



Next Steps in FY17

Compare the Cost Projections from Experts to Fuel Savings

- Obtain cost projections for various technologies from fuel cell experts -
 - Is there a tradeoff possible between cost and efficiency
- Sensitivity Analysis on following factors
 - H₂ cost
 - Discount rates
 - Pay back period (extended beyond 5 years?)



Summary -

Fuel cell and Storage technologies progress can lead to

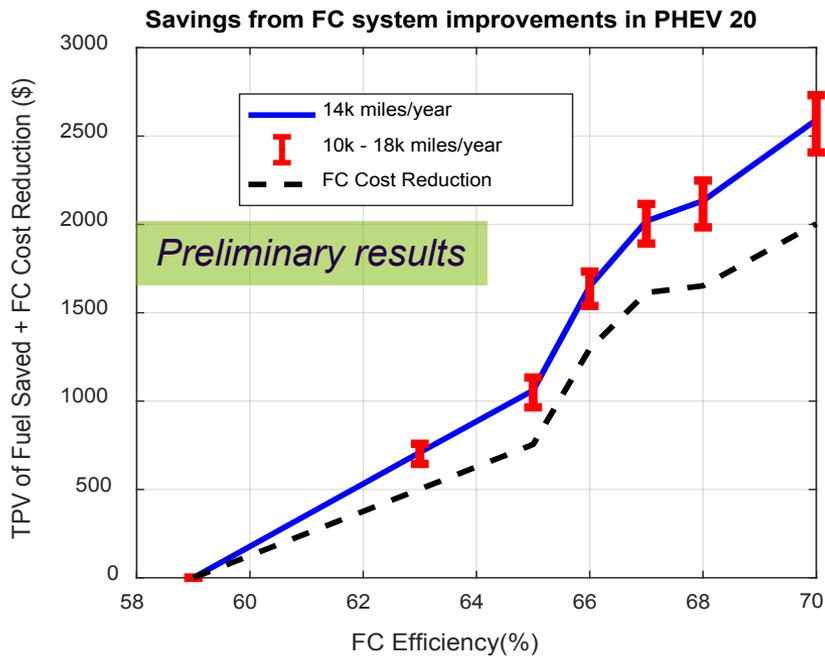
- ~\$700 in fuel cost savings over 5 year ownership period.
 - ~\$3300 in component cost reduction if DOE cost targets are met.
-
- Current fuel cell electric vehicles are nearly twice as efficient as the conventional alternatives including hybrids.
 - Economic feasibility is one of the main remaining hurdles for consumer acceptance
 - A process to quantify the incremental benefits for technology improvement has been developed.
 - Incremental improvements in technologies provide modest savings
 - 10 percentage point improvement in FC efficiency will save ~\$600 in fuel costs for a FCHEV over 5 years of ownership period
 - 60% improvement in H₂ storage capacity of tanks saves less than \$100 in fuel costs over a 5 year ownership period.
 - Component cost reduction is one of the main driving factor for FCEVs to become economically feasible.

Backup Slides

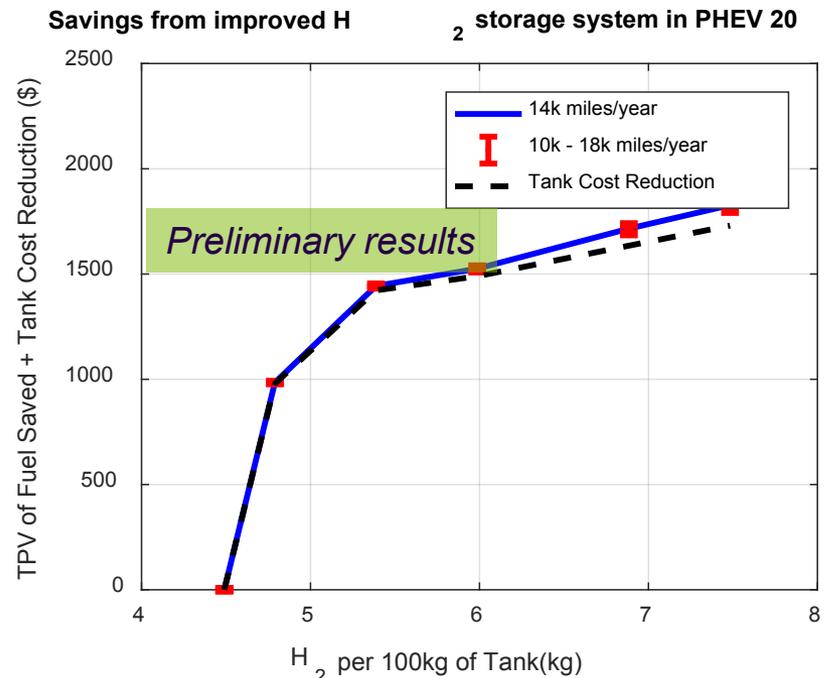
Savings for PHEV20

Fuel savings from weight reduction & efficiency improvements. Savings in component manufacturing cost

- Plots are shown for FC PHEV20
- A retail price equivalent correction is not done for the component cost savings



\$54/kW ← Cost of FC Power → \$30/kW



17 ← Storage Cost (\$/kWh) → 8

Fuel Cell & Storage Improvements Can Save Over \$4000* for FCEV Consumer

Compared to a present day FCHEV

▪ **Assumption:**

- Fuel system and Storage cost targets will be achieved along with the technology - improvement targets -

