Project ID # SA044 -

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

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ARGONNE NATIONAL LABORATORY

2017 DOE Hydrogen Program and Vehicle Technologies Annual Merit Review

June 7, 2016 -

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Project Overview -

Timeline	Barriers
• Project start date : Sep 2016 • Project end date : Aug 2017 • Percent complete : 75%	• 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**
• FY17 Funding : $120 • Percent spent : 75%	• 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
  - H_2 Tank : 4.5kg of H_2 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

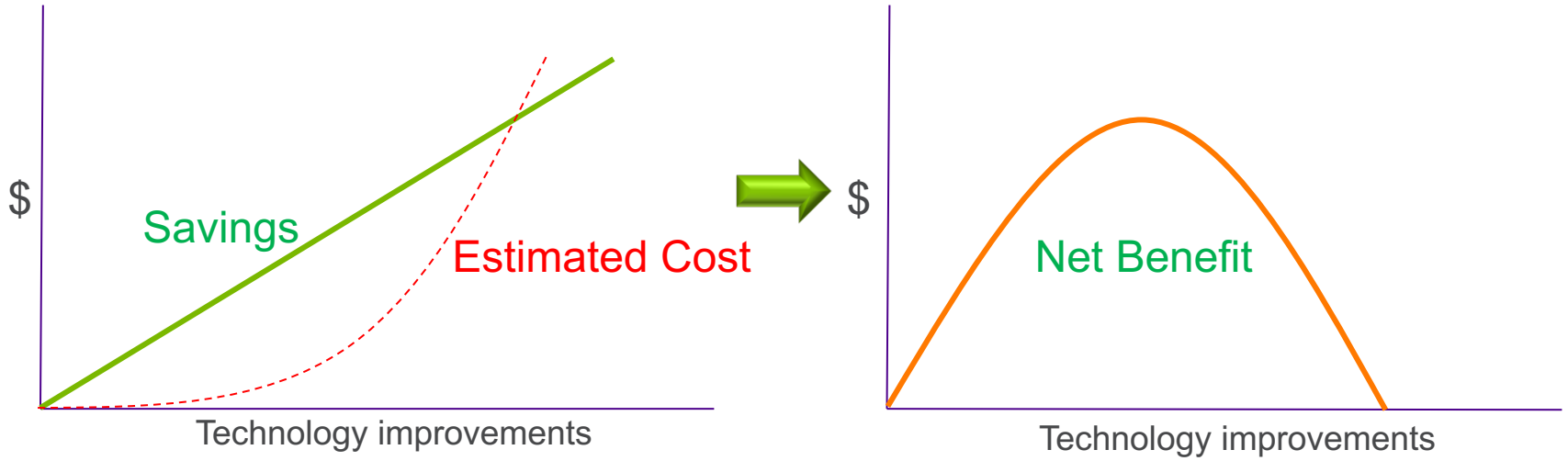
Parameter	Units	Ref	Expected Future Improvements					
FC System-Specific Power	W/kg	659	659	670	680	710	740	870
Peak FC Efficiency at 25% Rated Power	%	59	63	65	66	67	68	70

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

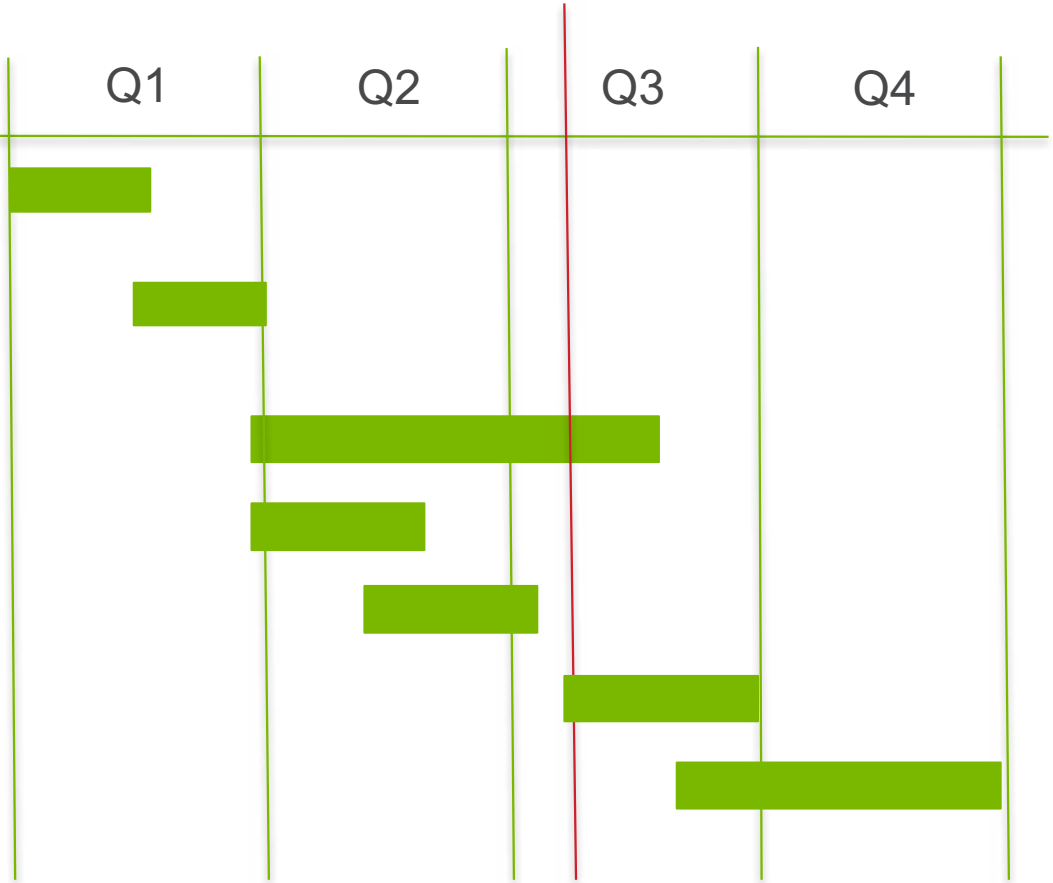
Quantify the Marginal Cost & Benefits from Fuel Cell System & Storage Technology Improvements

- 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



Vehicle definition

Sizing for technology progress assumptions

TPV Estimation

Fuel cell efficiency

Storage Technologies

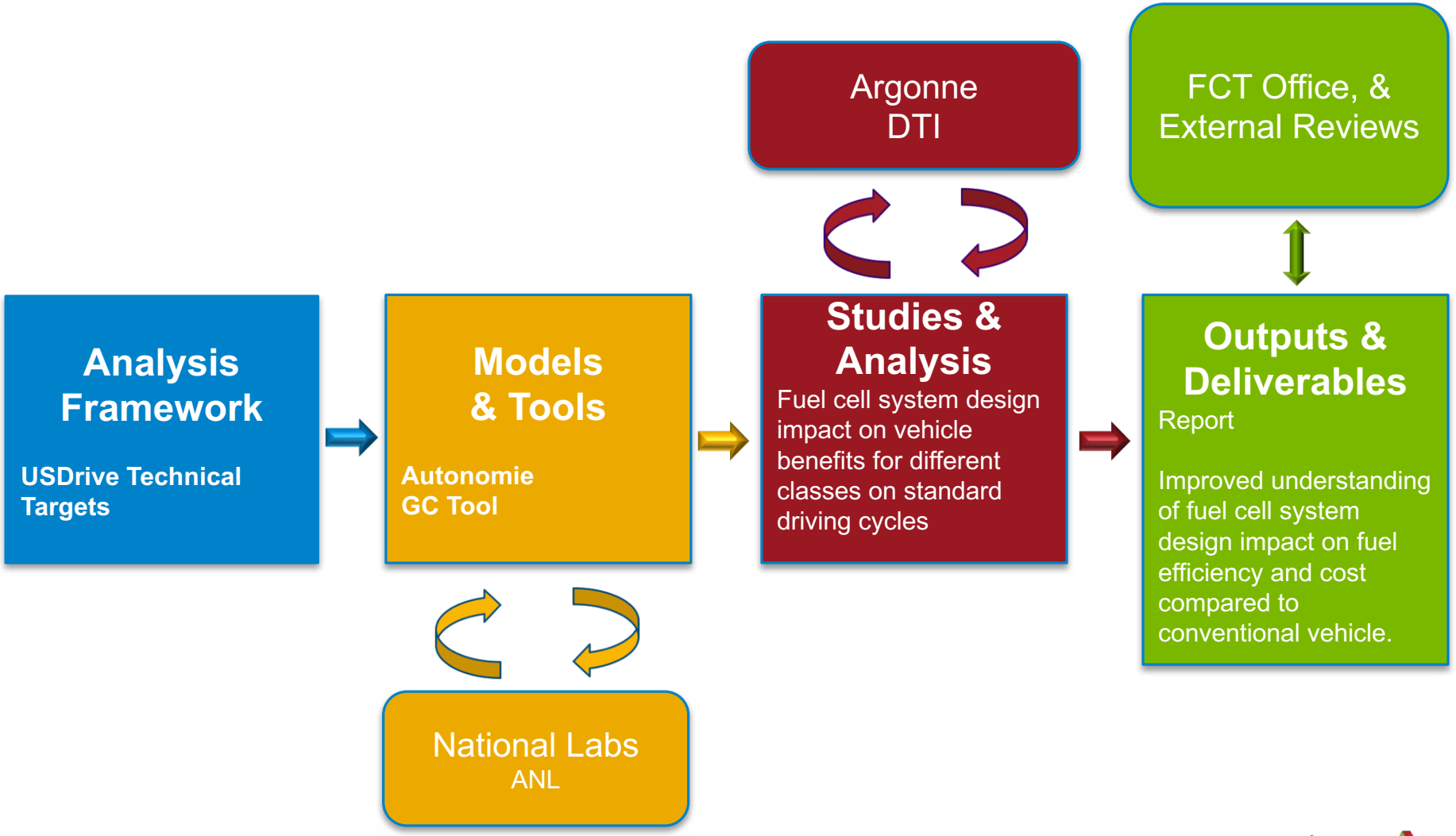
Cost vs. Benefit Analysis

Analysis & Reports

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

Approach

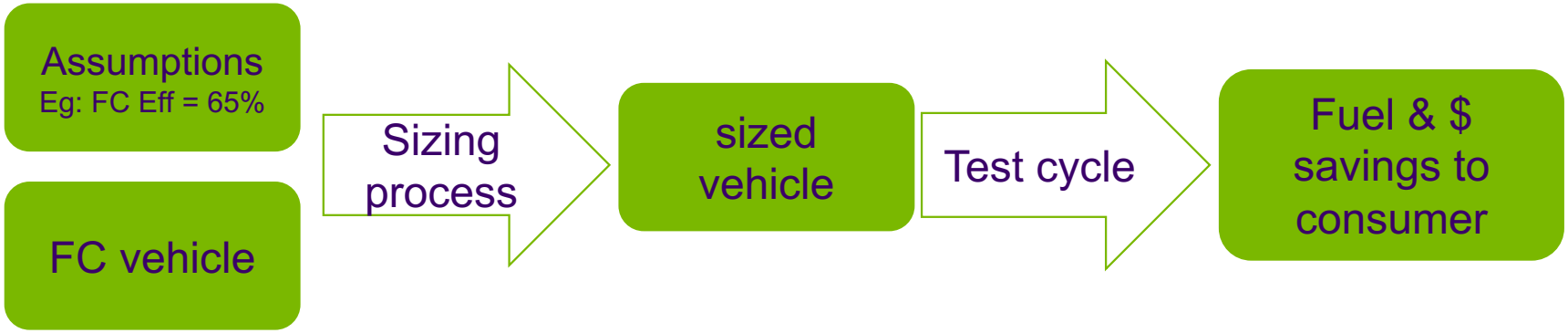
Impact of Fuel Cell System Peak Efficiency on Fuel Consumption and Cost



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.
  - H_2 systems improvements include weight ratio and increase in usable fraction of stored H_2



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 H_2 : $4/gge (delivered and dispensed)
  - TPV provides present $ value of the future fuel savings

Maximum Incremental Component Cost Resulting from Fuel Savings

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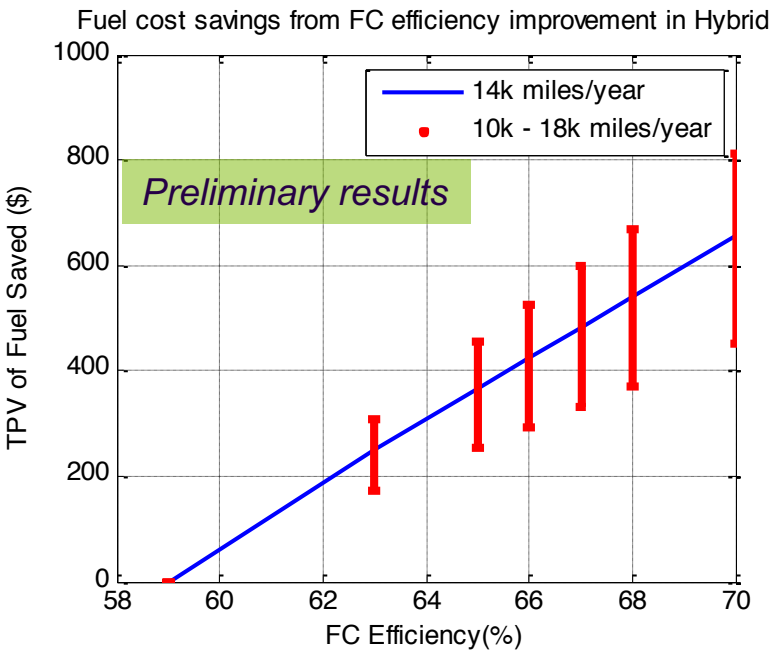
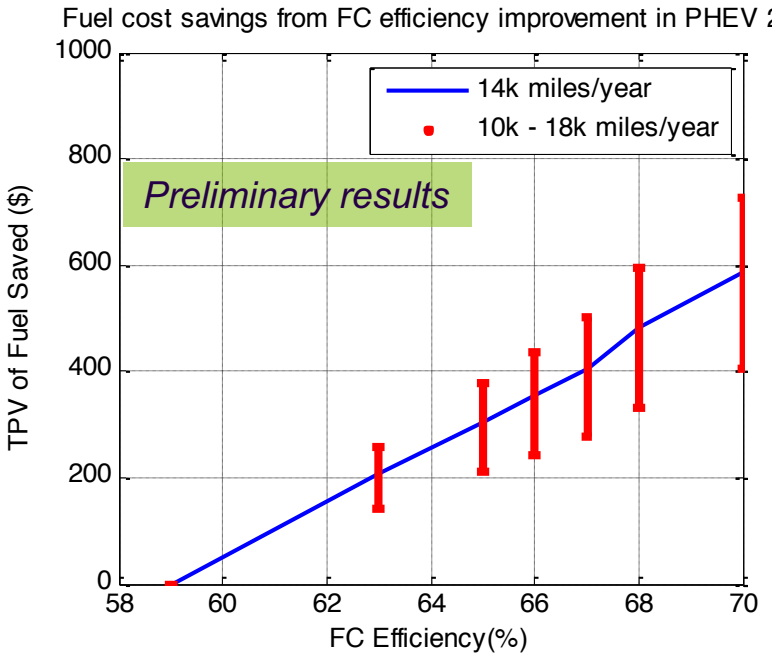
Technical Accomplishments

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





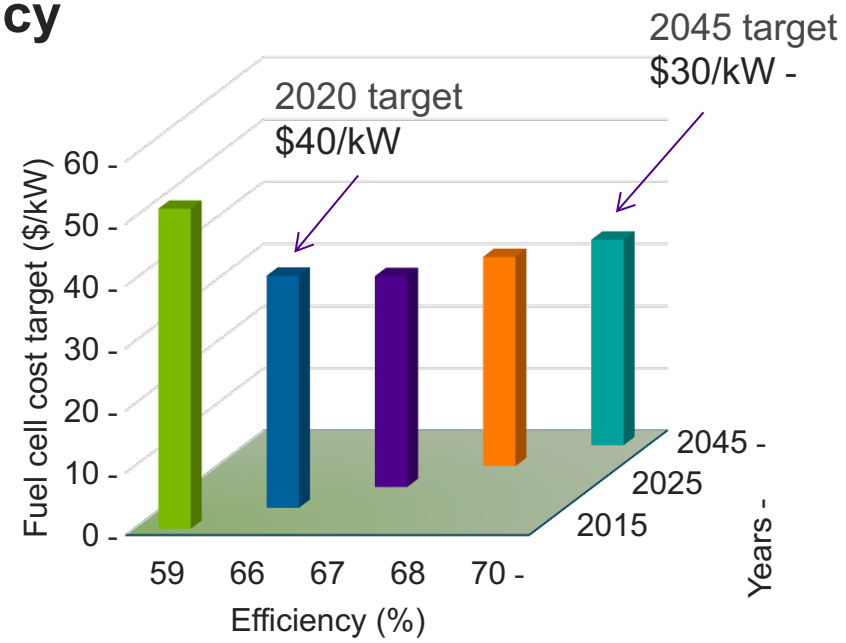
*BaSce 2015 technology is considered as the baseline for all cost saving estimates

Technical Accomplishments

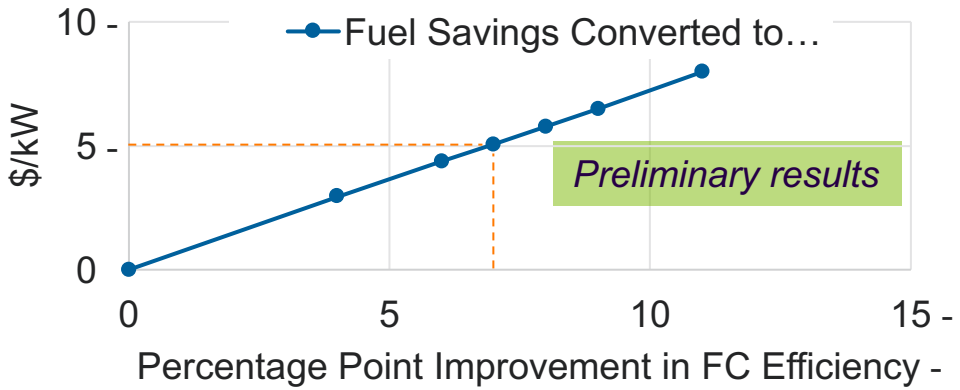
Allowable Cost for FC Efficiency Improvements

~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 -



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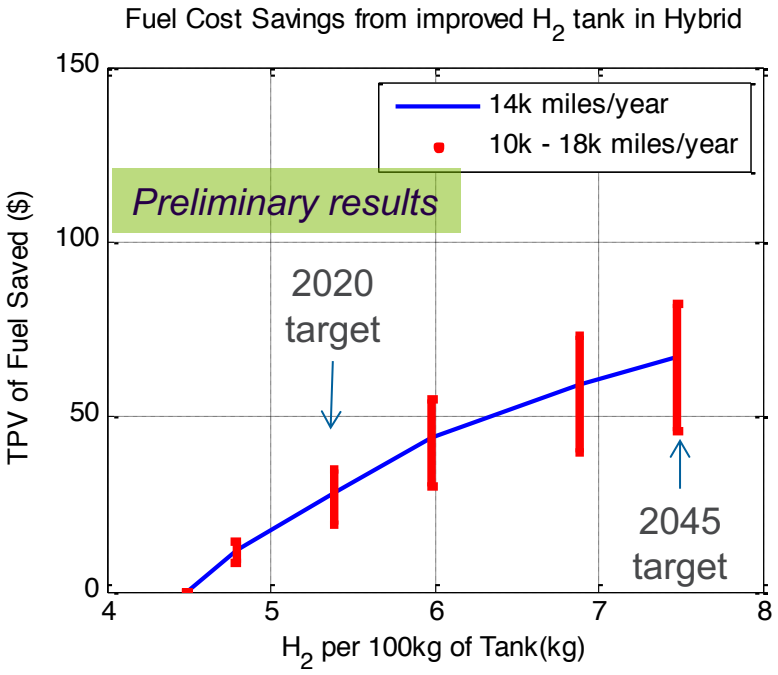
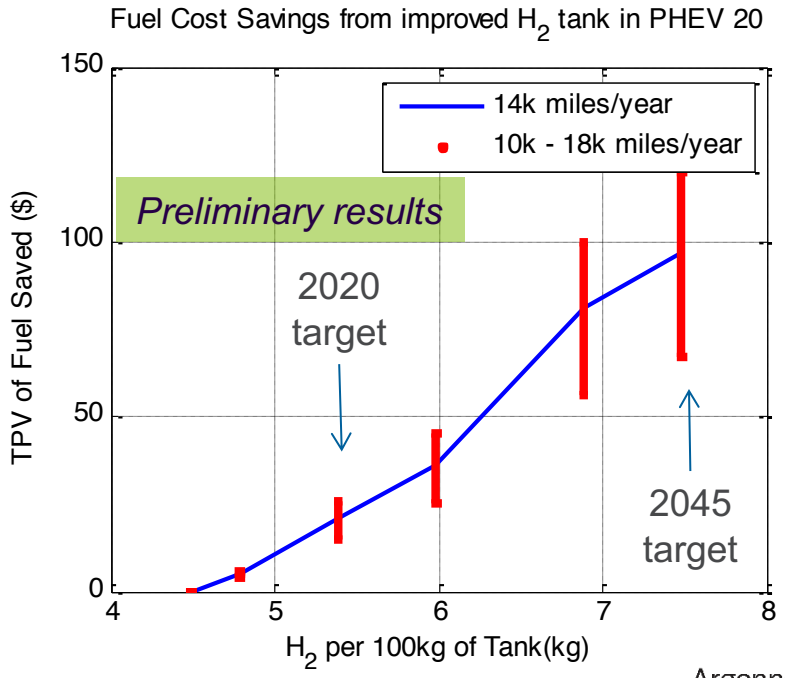
Technical Accomplishments

Impact of H2 Storage Improvements

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.
- 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.





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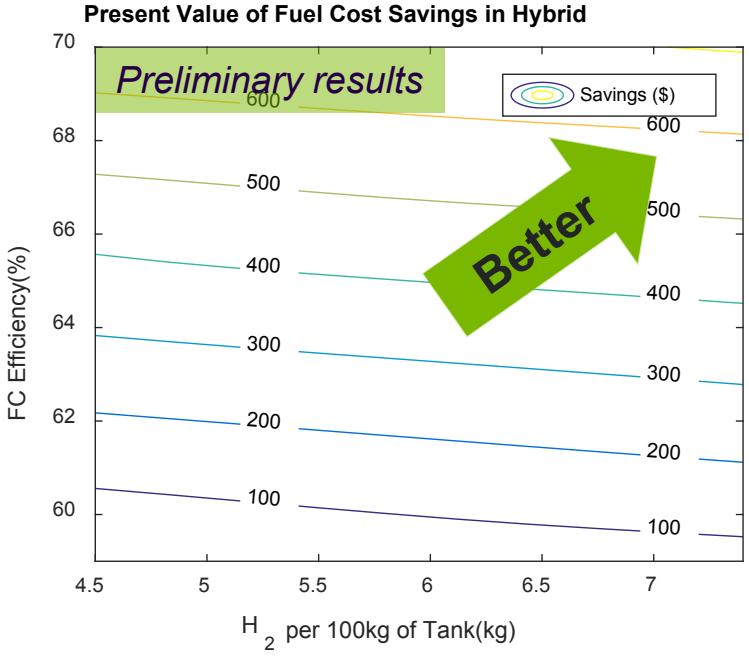
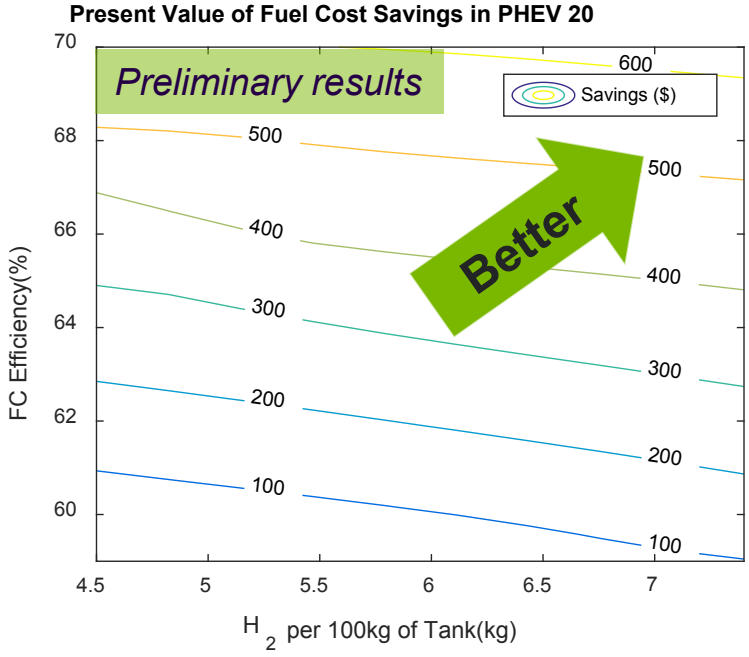
Technical Accomplishments

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.





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Impact of Component Cost Reduction Based On FCTO Targets

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Impacts of FCTO Cost Reduction Targets -

Cost targets from FCTO Benefit Analysis

Parameter	Units	2015	2020			2025			2030			2045		
		low	low	med	high	low	med	high	low	med	high	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).

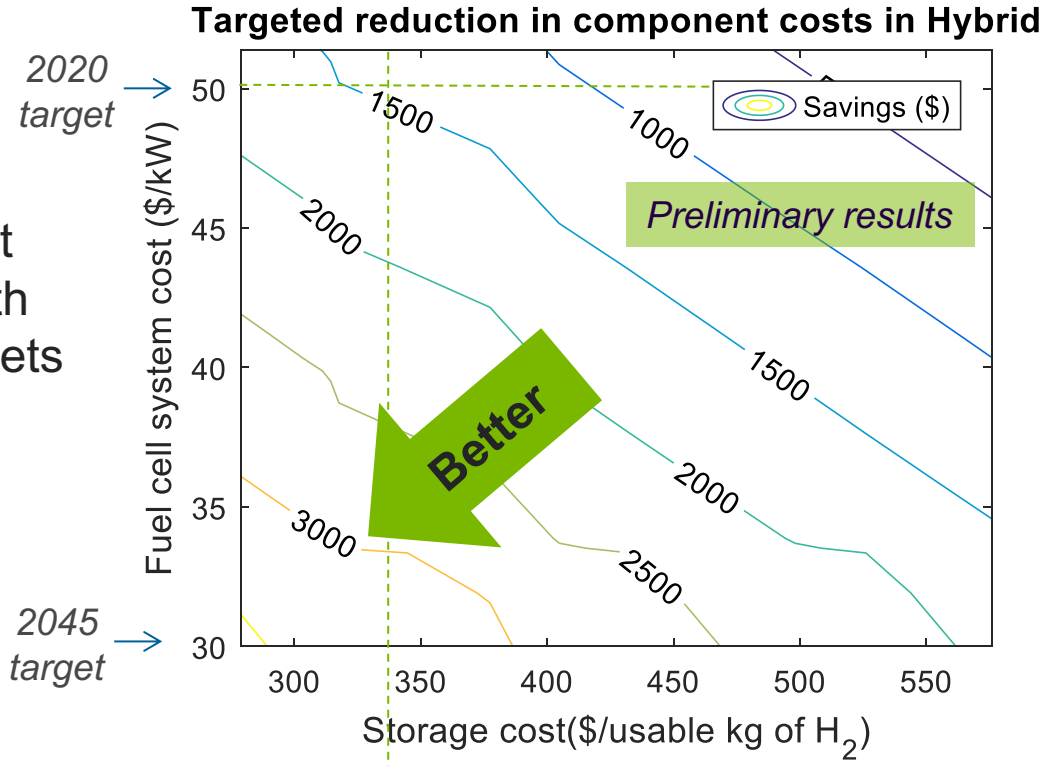
Parameter	Units	2015	2020			2025			2030			2045		
		low	low	med	high	low	med	high	low	med	high	low	med	high
System Capacity	Useable kWh/kg	1.5	1.5	1.6	1.8	1.6	1.7	2.0	1.6	1.8	2.3	1.7	2.0	2.5
	Useable kg H2/kg of tank	0.045	0.045	0.048	0.054	0.048	0.051	0.060	0.048	0.054	0.069	0.051	0.060	0.075
Tank Cost	$/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 savings expected from fuel cell technology improvements

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



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

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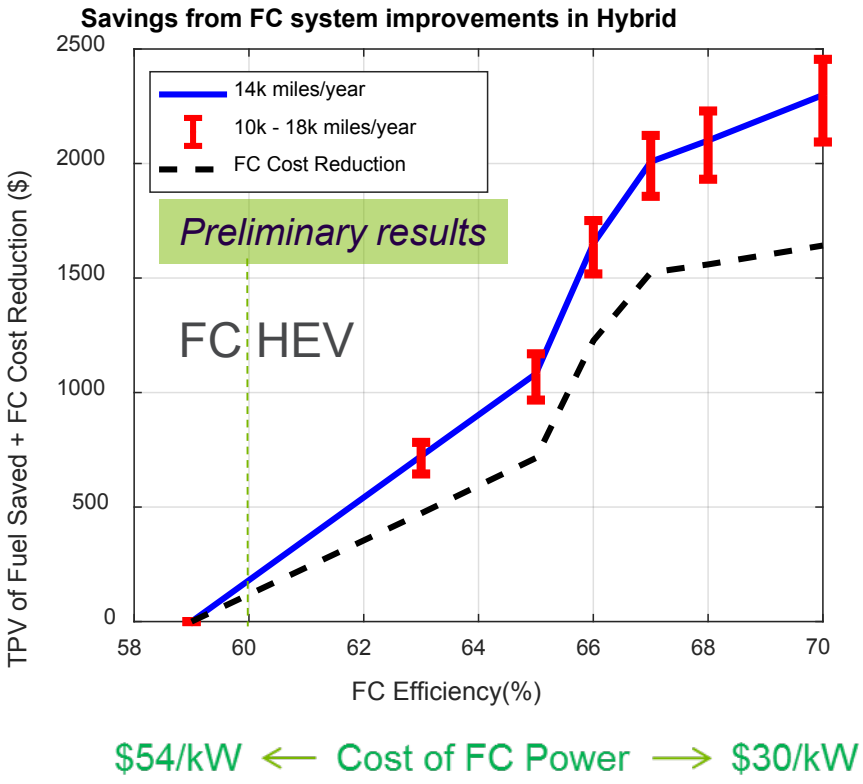
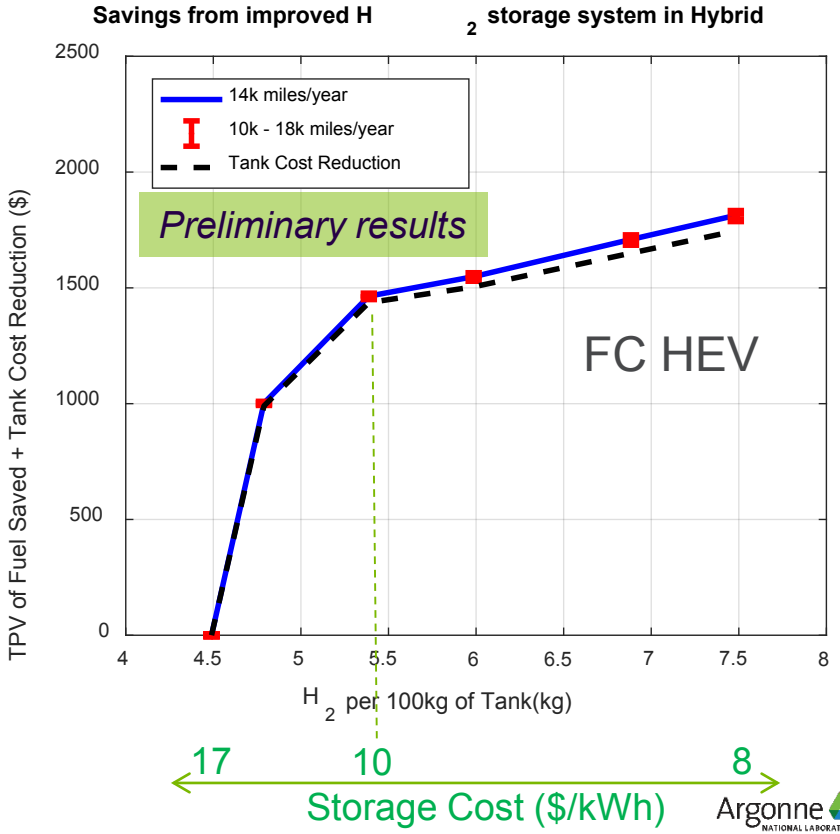
Technical Accomplishments

Achieving DOE Cost Targets Will Produce Substantial Savings For Consumer

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



$54/kW ← Cost of FC Power → $30/kW



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Storage Cost ($/kWh)

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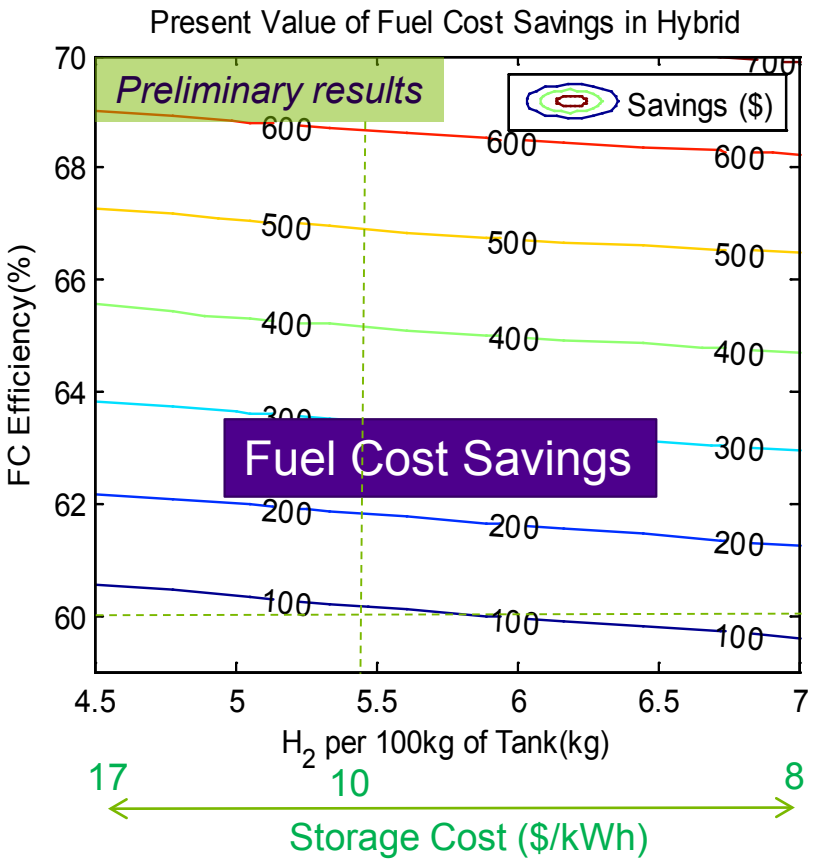
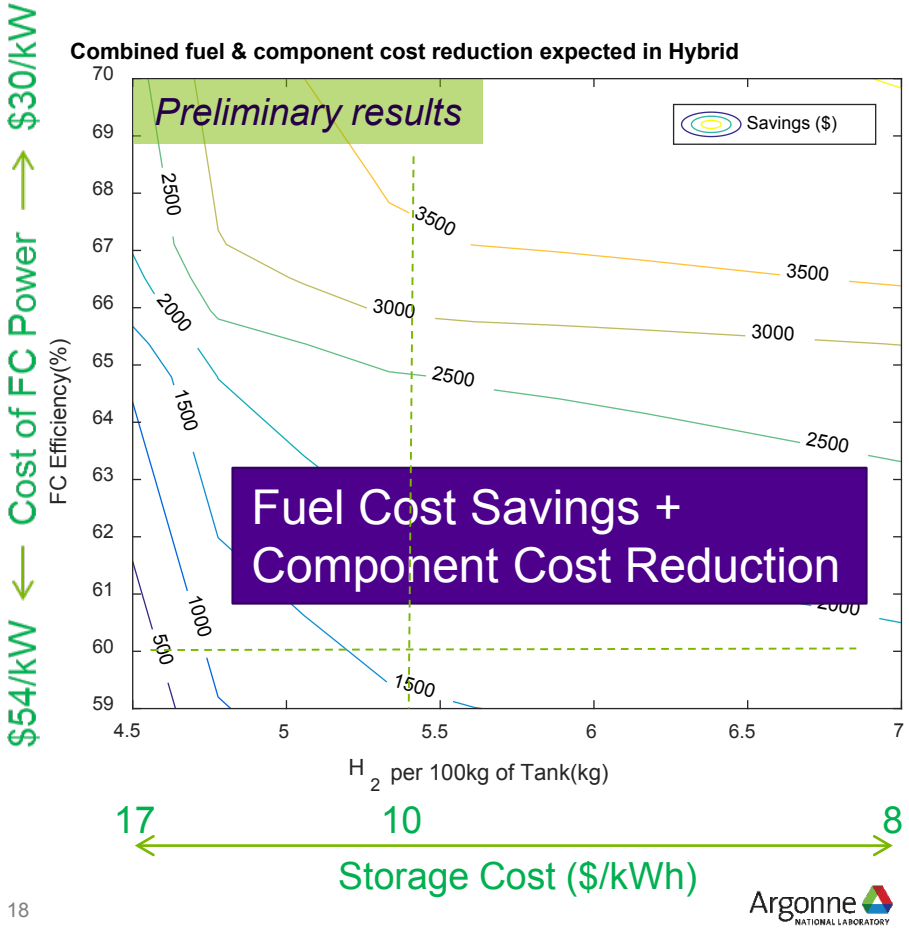
Technical Accomplishments

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 H_2 : $4/gge





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Response to Previous Year Reviewers' Comments on a Related

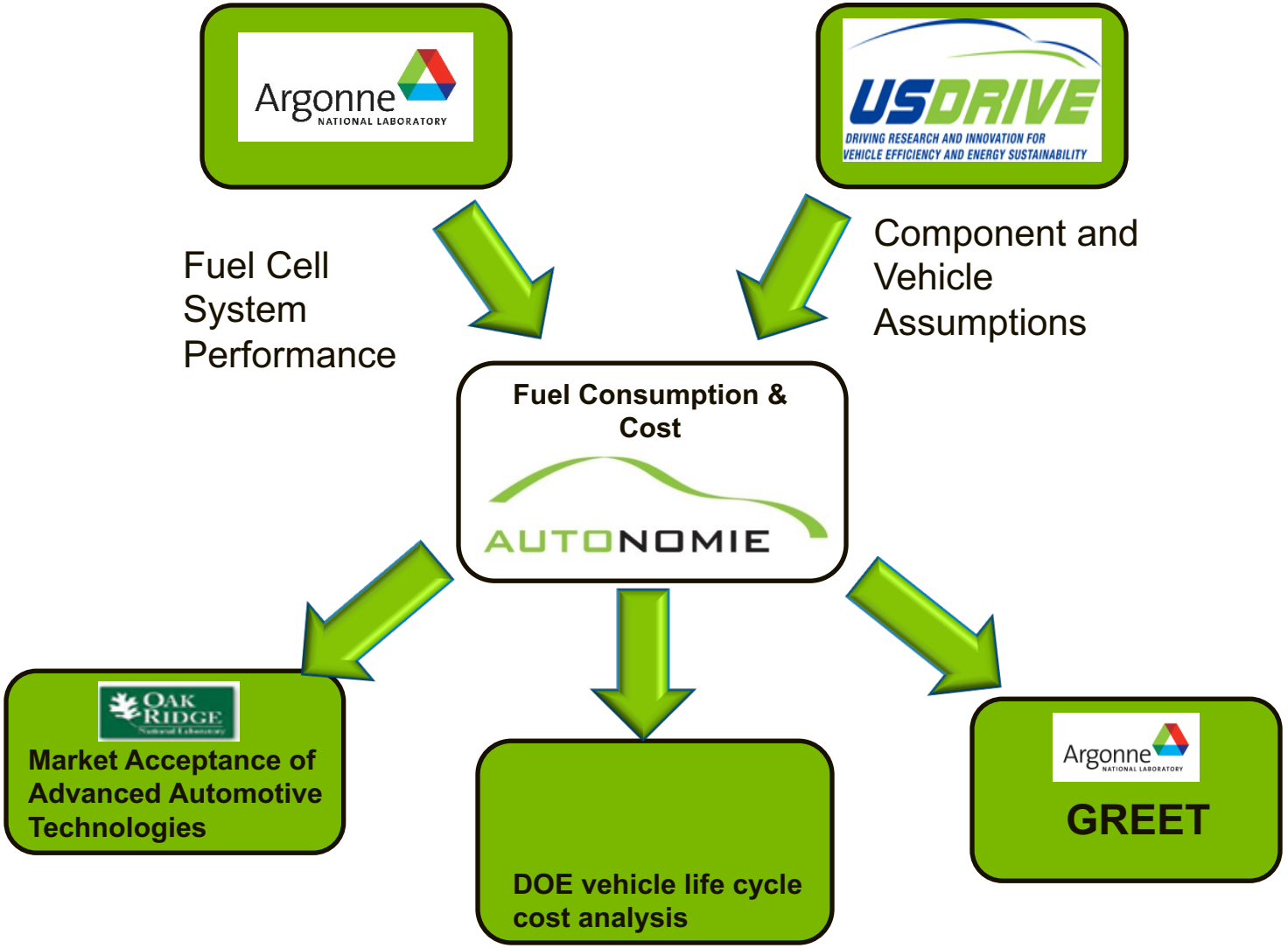
This particular project was not reviewed last year. Analysis of FCTO targets and their impact on feasibility of FCEVs was reviewed.

- 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.*

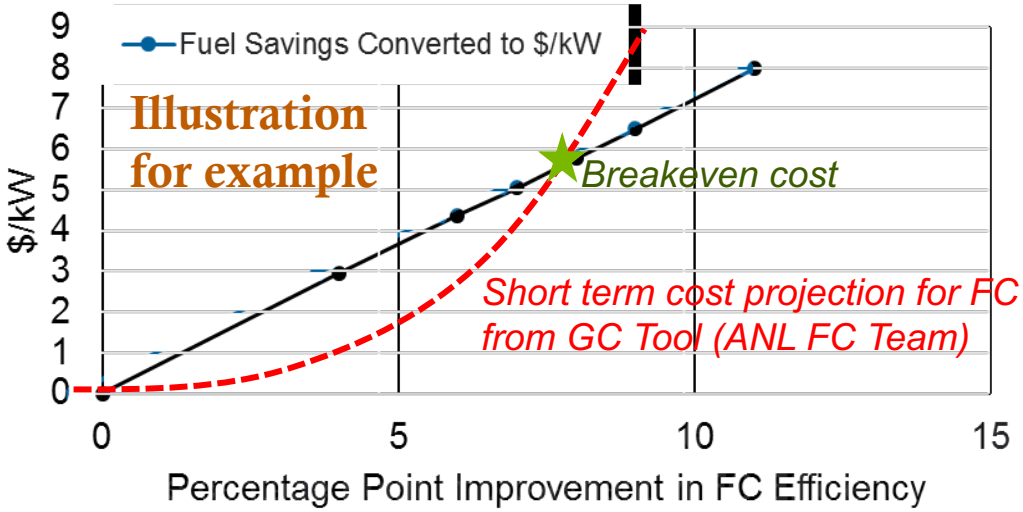
Collaboration and Coordination with Other Institutions

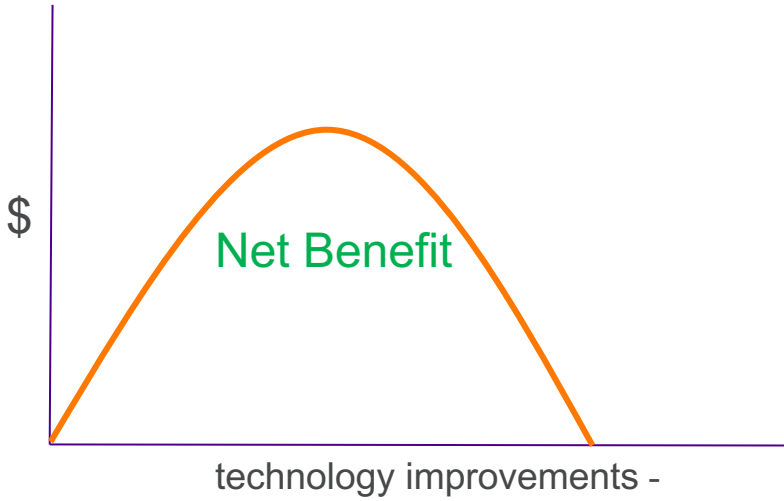


Next Steps in FY17

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
  - H_2 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.**

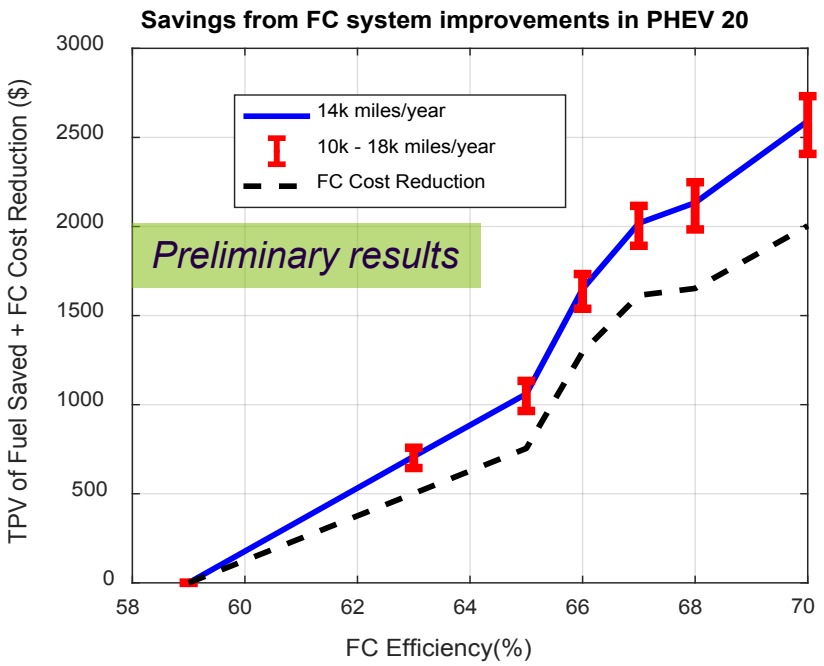
- Current fuel cell electric vehicles are nearly twice as efficient as the conventional alternatives including hybrids.
  - Economic feasibility is one of the main remaining hurdles for consumer acceptance
- A process to quantify the incremental benefits for technology improvement has been developed.
- 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 H_2 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



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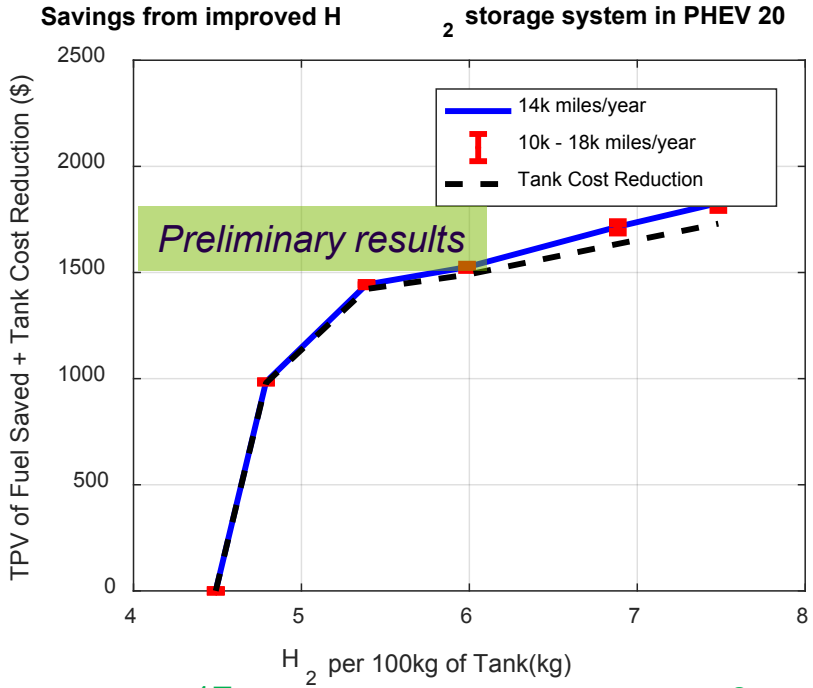

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Storage Cost ($/kWh)

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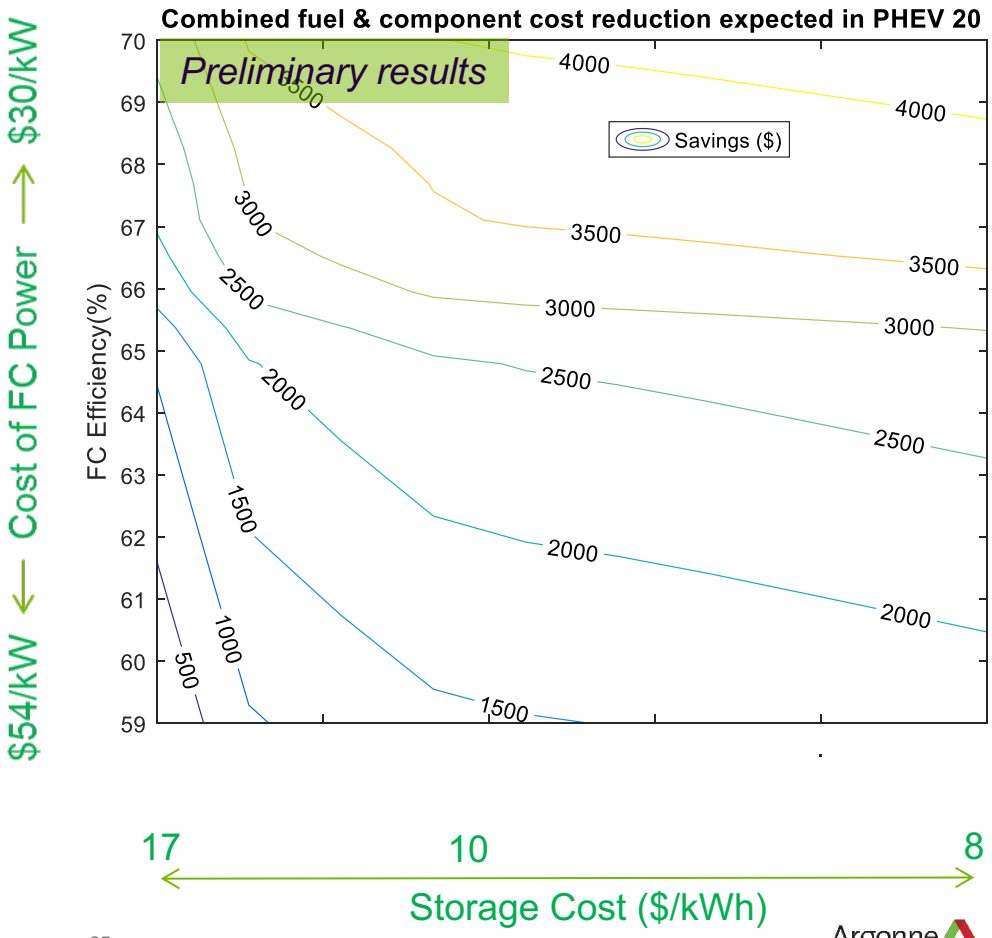
Fuel Cell & Storage Improvements Can Save Over $4000* for FCEV Consumer

Compared to a present day FCHEV

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



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