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Impact of Fuel Cell and H_2 Storage Improvements on FCEVs

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Project ID # SA044

Project Overview

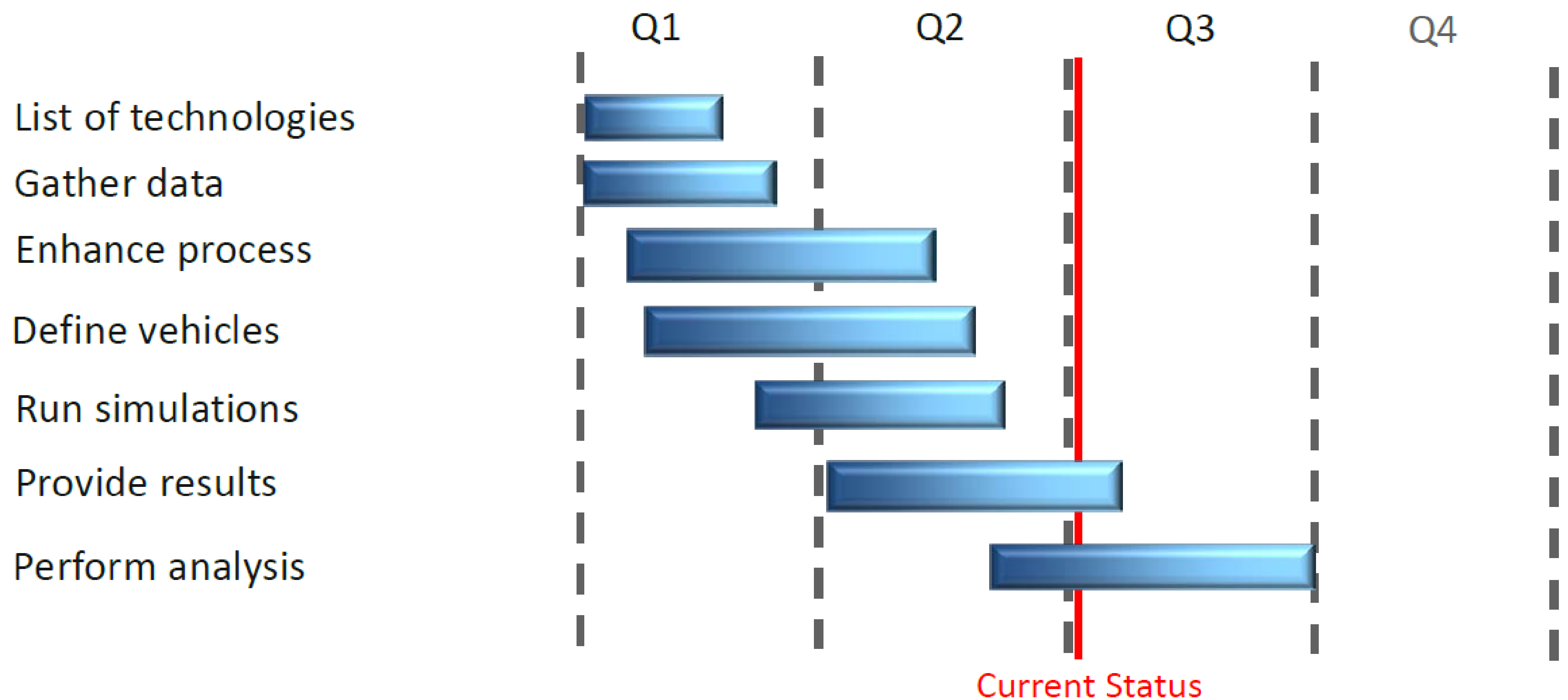
Timeline	Barriers
Start date : Sep 2015 End date : Aug 2016 Percent complete : 90%	• Lack of Fuel Cell Electric Vehicle and Fuel Cell Bus Performance and Durability Data (A) • Hydrogen Storage (C) http://energy.gov/sites/prod/files/2015/06/f23/fcto_myrdd_tech_valid.pdf
Budget	**Partners**
▪ FY16 Funding : $125K ▪ Percent Utilized : 80%	▪ Argonne fuel cell system experts

Relevance

Quantify the impact of fuel cell system improvements on energy consumption and economic viability of fuel cell powered vehicles

- BaSce analysis shows that by 2025, Fuel Cell Electric Vehicles (FCEVs) may have similar or lower cost of ownership as the fossil fuel powered vehicles.
- Many technologies that help FCEVs are expected to evolve during this time.
  - Eg. light weighting, improved aerodynamics
- Do FCEVs depend on ‘other’ technologies to be viable?
  - If fuel cell technology development meet their targets, and other technologies stagnate, can FCEVs be economically feasible
- Analysis will reveal :
  - Impact of fuel cell stack improvement on cost of driving FCEVs
  - Impact of H_2 storage improvement on cost of driving FCEVs
  - Impact of fuel cell system improvement on cost of driving FCEVs
  - Are the current fuel cell & storage technology targets sufficient to make FCEVs viable even with current vehicle technology

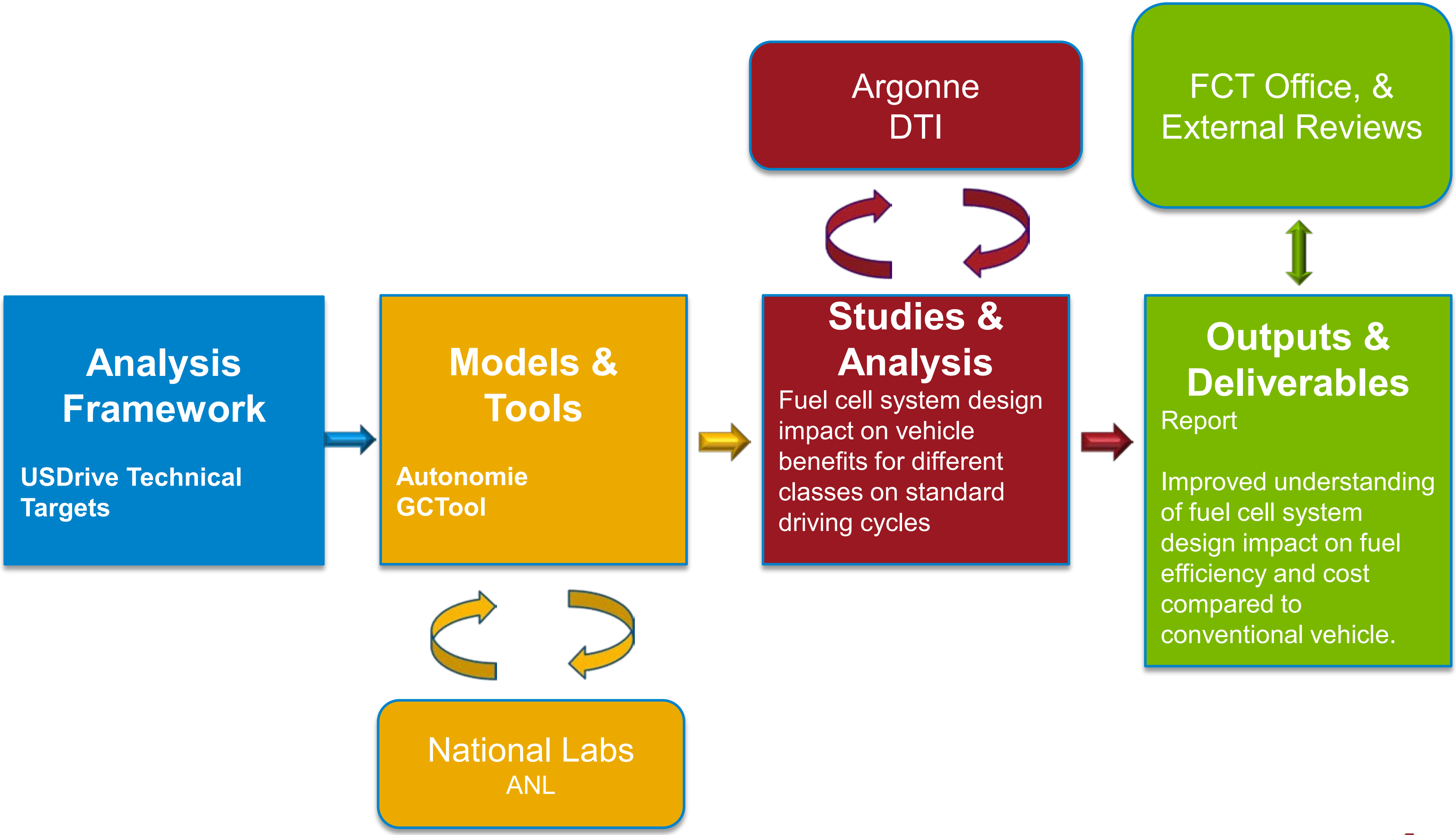
Milestones



Preliminary results are available now.
Completion of analysis and reports are expected by end of FY16

Approach

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



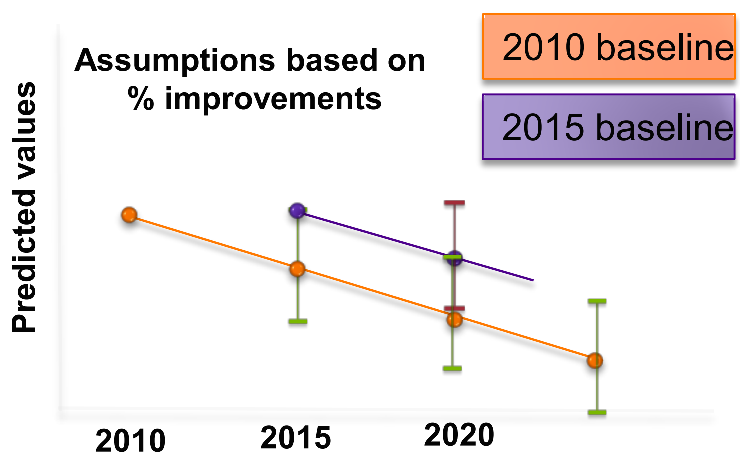
Approach

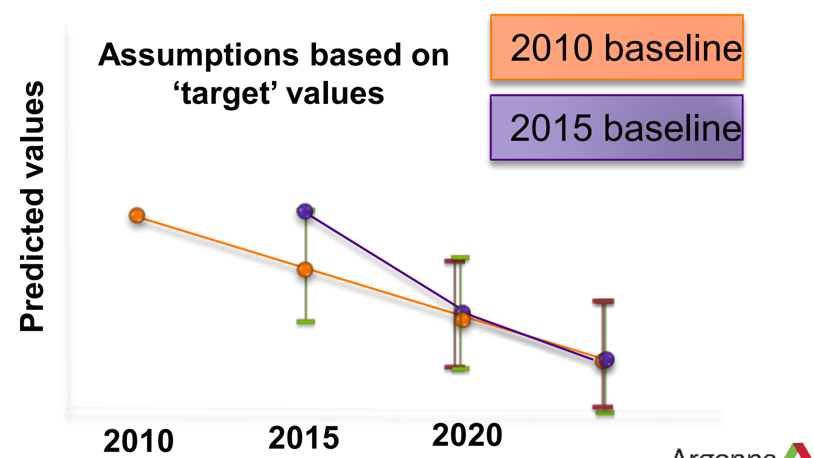
The objective is to evaluate the impact of fuel cells and storage technology, on cost & energy consumption of FCEVs.

- Size the vehicles to meet similar vehicle technical specifications (i.e. performance, range…) with following assumptions.
  - MY2015 FC HEV with
    - accelerated H_2 storage improvements from MY2020, 2025, 2030, and 2045
    - accelerated FC system improvements from MY2020, 2025, 2030, and 2045
    - accelerated FC & H_2 storage improvements from MY2020, 2025, 2030, and 2045
- Estimations using EPA's Combined 2 cycle procedure (UDDS & HWFET)
- Compare 'Fuel Consumption', 'Vehicle Cost' & 'LCOD'
- Scope of the study is restricted to midsize light-duty vehicles
  - Contributions from 'non fuel-cell' technologies is not considered in this study.

Approach
Key Similarities and Differences with FY15 Study

- Estimates/Assumptions for technology improvement remain the same
  - target value for a particular year (eg: specific power of battery or fuel cells)
  - % improvement over previous years (eg: weight reduction)
- In FY15 study, the reference vehicle was from 2010.
- In this study, 2015 'low uncertainty' (i.e. most likely) case is taken as the baseline
  - This change in baseline value affects nearly every prediction.
    - Vehicles are heavier than the FY15 '2015 medium uncertainty'
    - Larger fuel cells, more H_2 storage, larger batteries, higher cost
    - Overall trend in improvement remains the same

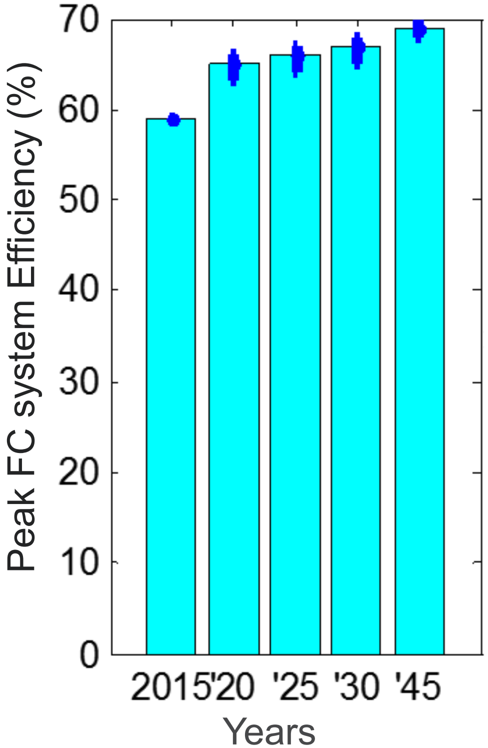


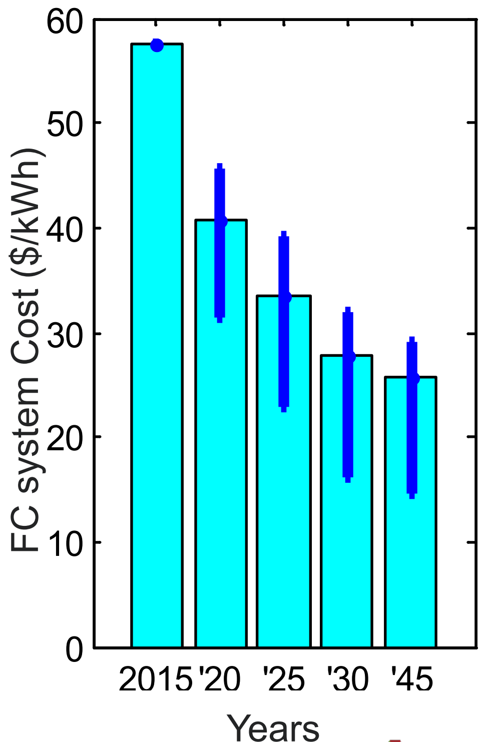


Assumptions
Fuel Cell System Assumptions – Efficiency & Cost

Parameter	Units	2015	2020			2025			2030			2045		
			low	Med	high	low	Med	high	low	Med	high	low	Med	high
Peak Fuel Cell System Efficiency	%	59	63	65	66	64	66	67	65	67	68	68	69	70
Platinum Price	$/Troy OZ	$1,500	$1,500			$1,500			$1,500			$1,500		

- ***Fuel Cell Cost = (x*1246.5*(Stack.UnitsPerYr)^-0.2583 +(Pt.Price*y)) *Fuel.Cell.kW* (Fuel.Cell.kW/Base.80kW)^z***
  - (x,y,z): Coefficients
  - Stack.UnitsPerYr = 500,000
  - Pt.Price: Platinium Price
  - Fuel.Cell.kW: Fuel Cell Power
- Costs are assumed for high production volumes

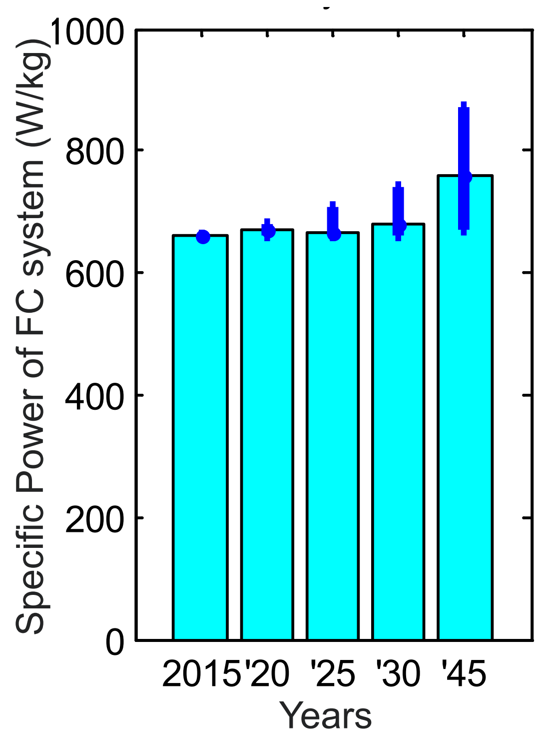




Assumptions
Fuel Cell System Assumptions – Weight & Volume

Parameter	Units	2015	2020			2025			2030			2045		
			low	Med	high	low	Med	high	low	Med	high	low	Med	high
Specific Power FC System	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

- ***FuelCell.Weight = FuelCell.kW / Specific Power FC System***
- *Volume is not considered in this analysis*



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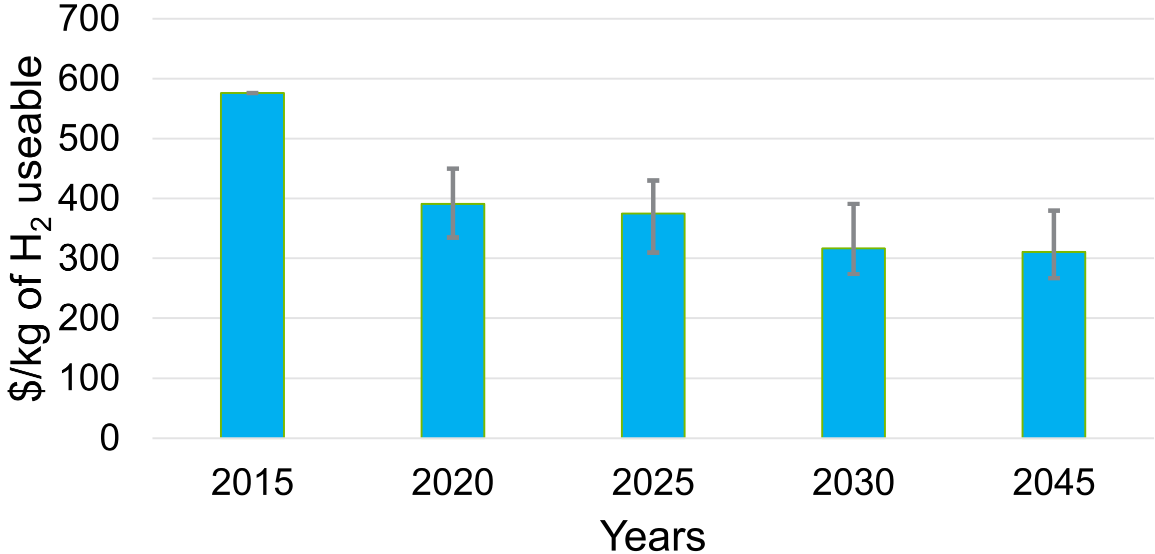
Assumptions

Hydrogen Storage Assumptions

Parameter	Units	2015	2020			2025			2030			2045		
			low	Med	high	low	Med	high	low	Med	high	low	Med	high
System Gravimetric Capacity	Useable kWh/kg	1.5	1.5	1.6	1.8	1.6	1.7	2	1.6	1.8	2.3	1.7	2	2.5
	Weight % of H_2	4.5	4.5	4.8	5.4	4.8	5.1	6	4.8	5.4	6.9	5.1	6	7.5
Cost	$/kg H_2 useable	576	450	391	335	430	375	310	391	317	274	380	311	267
	$ / kWh stored	17.3	13.5	11.7	10.1	12.9	11.3	9.3	11.7	9.5	8.2	11.4	9.3	8.0
% H_2 used in Tank	%	96	96	96	96	96	96	97	96	97	97	96	97	97

H_2.Storage.Cost = Cost.Coefficient * Fuel.Mass

H_2.Storage.Mass = Fuel.Mass / wt. % of H_2



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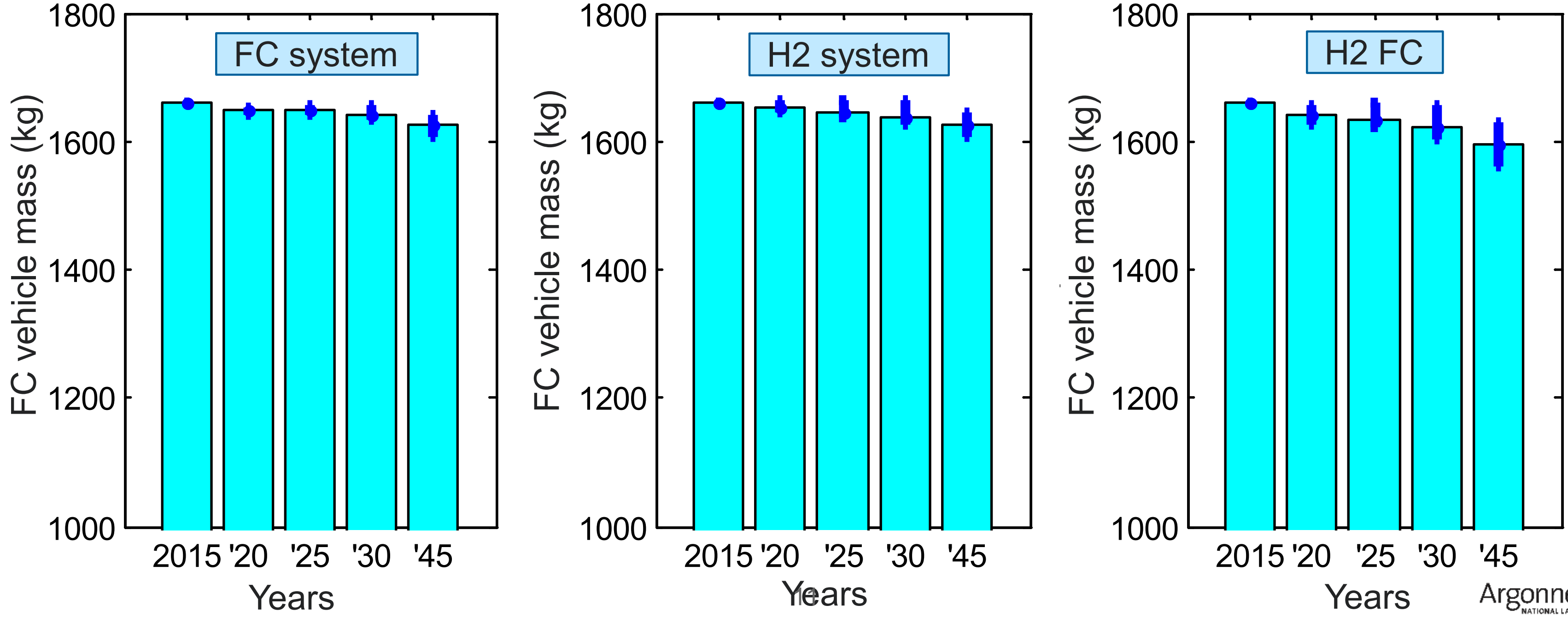
Technical Accomplishments

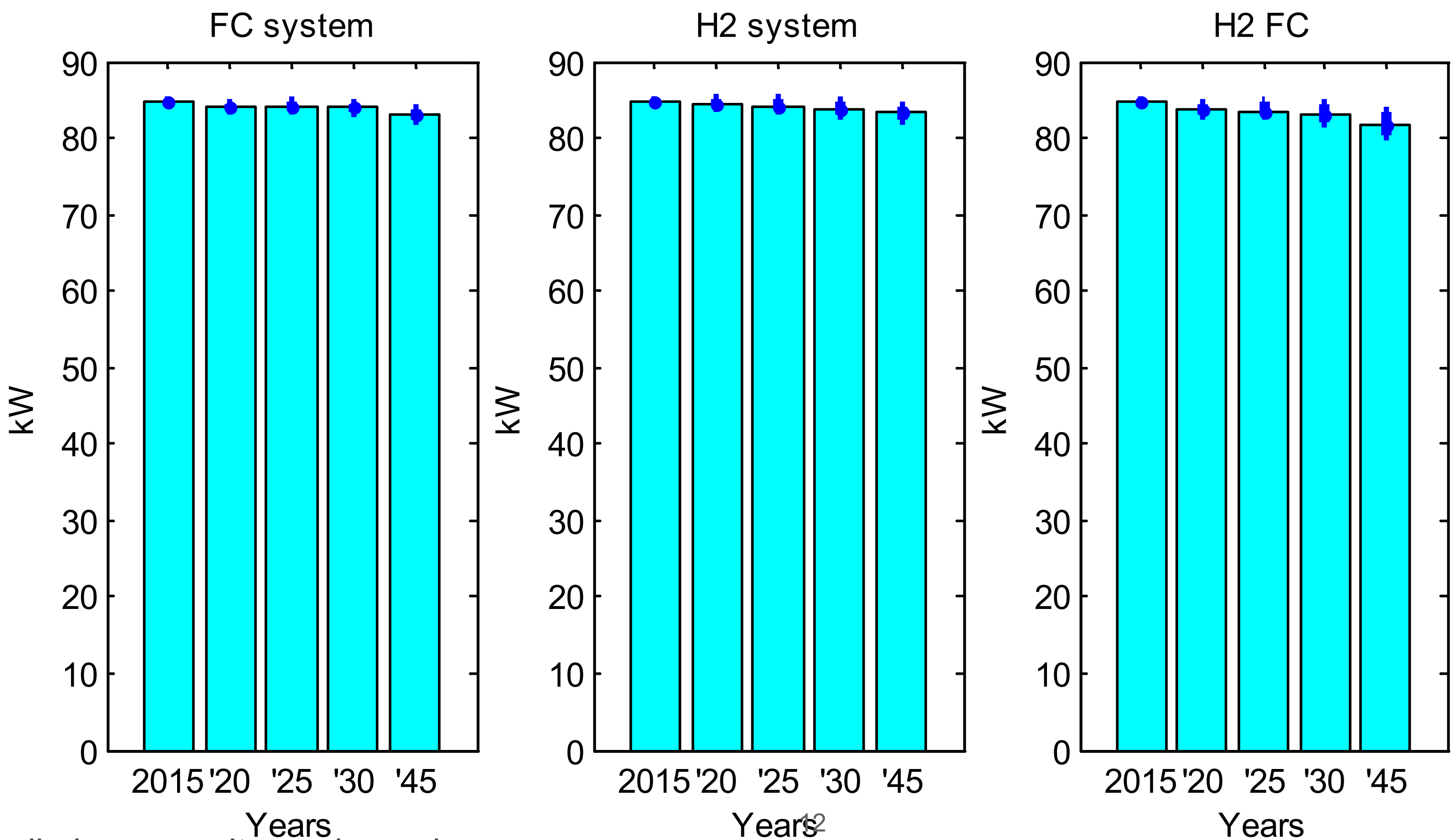
FCEV Vehicle Weight

- This study considers 3 scenarios
  - Fuel Cell (FC) System Impact : Fuel cell system improves over time
  - Hydrogen Storage (H2) System Impact : Hydrogen Storage system improves over time
  - Combined (H2 FC) Impact : Both Fuel cell & Hydrogen systems improve over time
- All other vehicle technologies remain as they are in 2015
- Without light weighting and improvement in other component technology, FC vehicle weight reduction is possible from
  - Lower FC system weight, Higher FC efficiency results in lower H2 requirement & smaller and lighter H2 tanks



Technical Accomplishments
Fuel Cell Systems Power

- Fuel cell system and hydrogen storage technology improvements alone will reduce the vehicle power requirement by 3.5% in next 30 years
  - Contributing factors are
    - Lower vehicle weight
    - Higher efficiency



*preliminary results, under review

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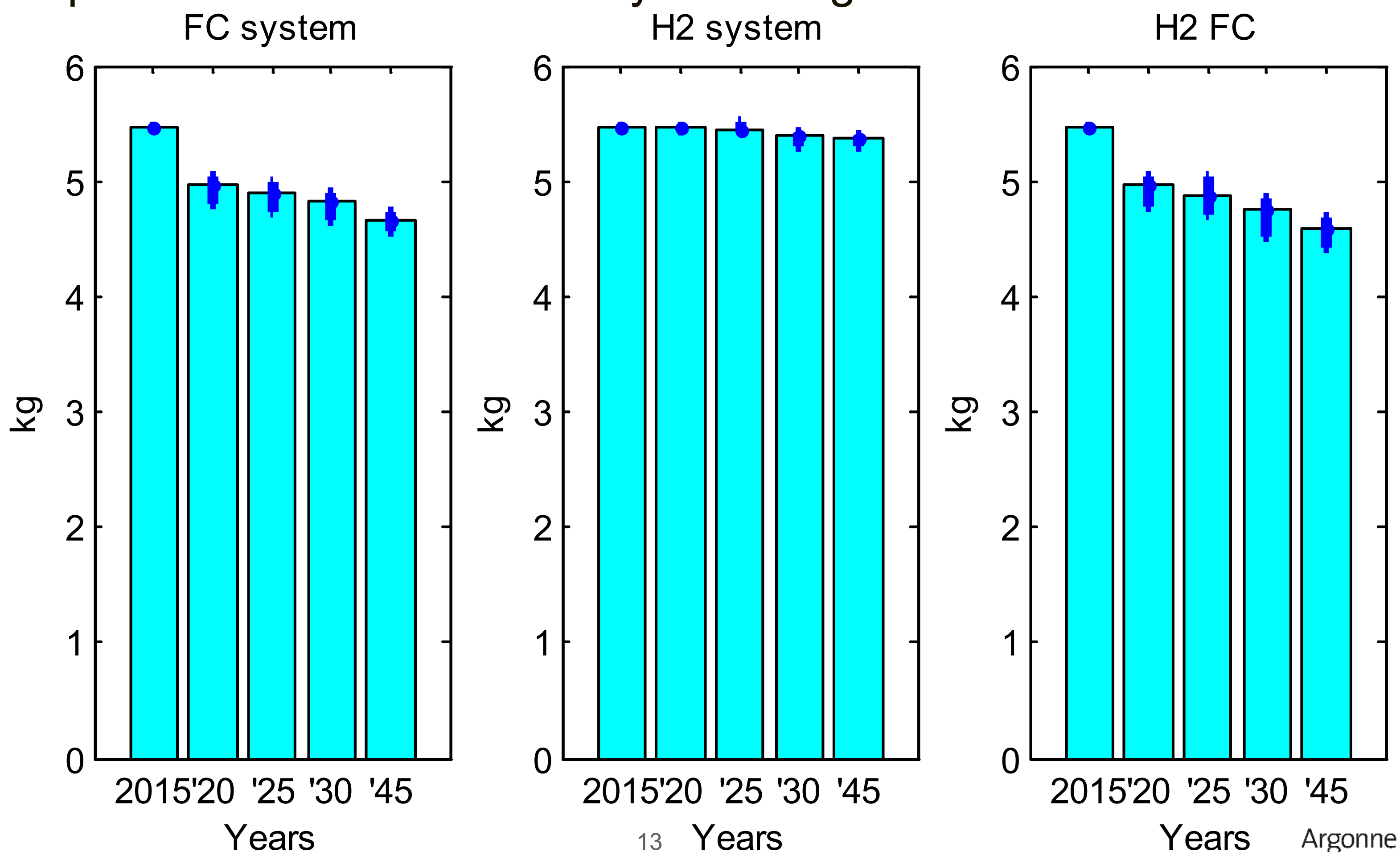
Technical Accomplishments

Hydrogen Fuel Weight

- Required on-board hydrogen mass could drop by 15%, due to the fuel cell system technology improvements.
  - Contributing factors
    - Improvements in FC efficiency and weight



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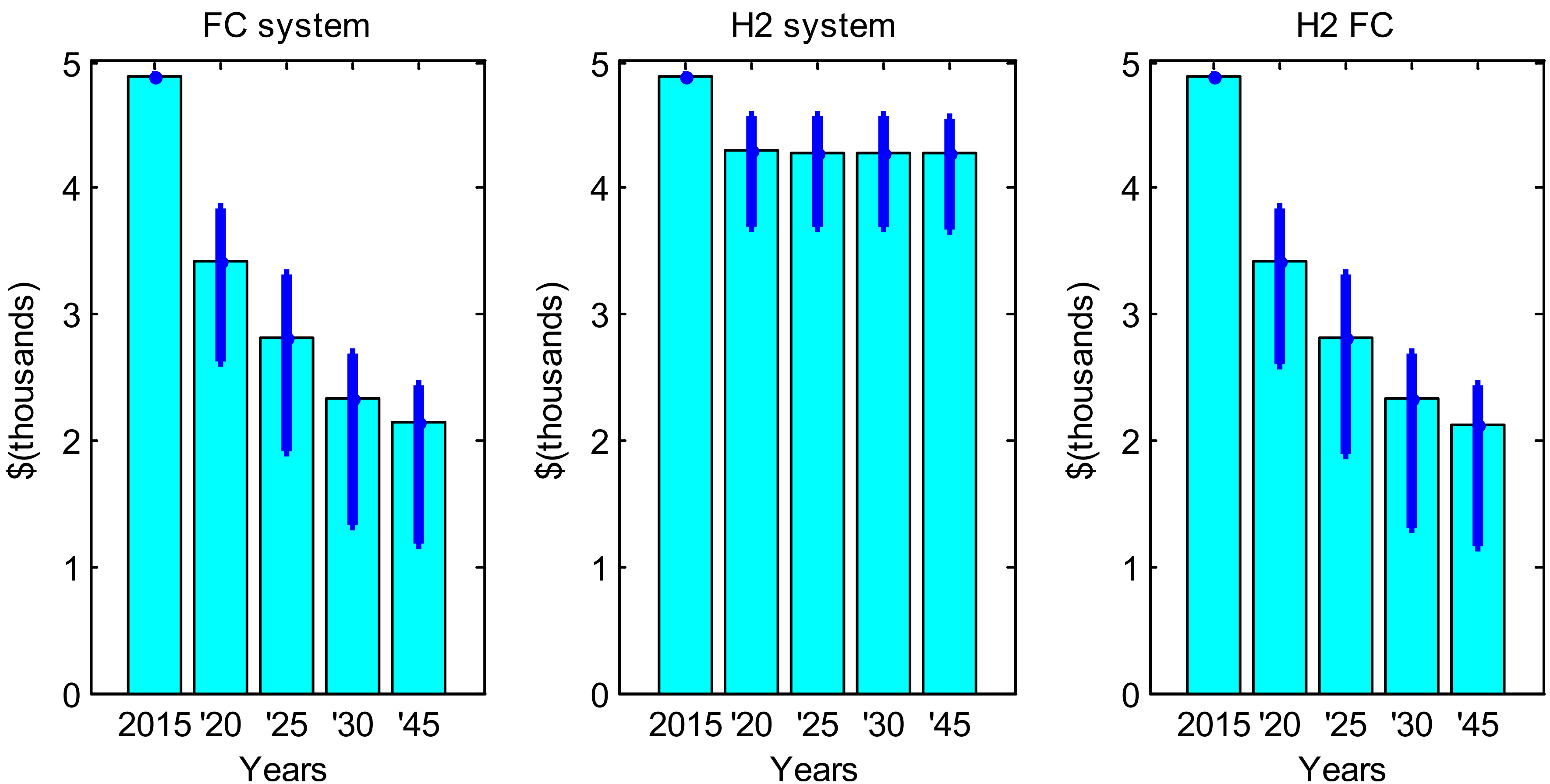
Technical Accomplishments
Fuel Cell System Cost

- Fuel cell system cost could decrease by over 50%, due to the fuel cell system technology improvements.



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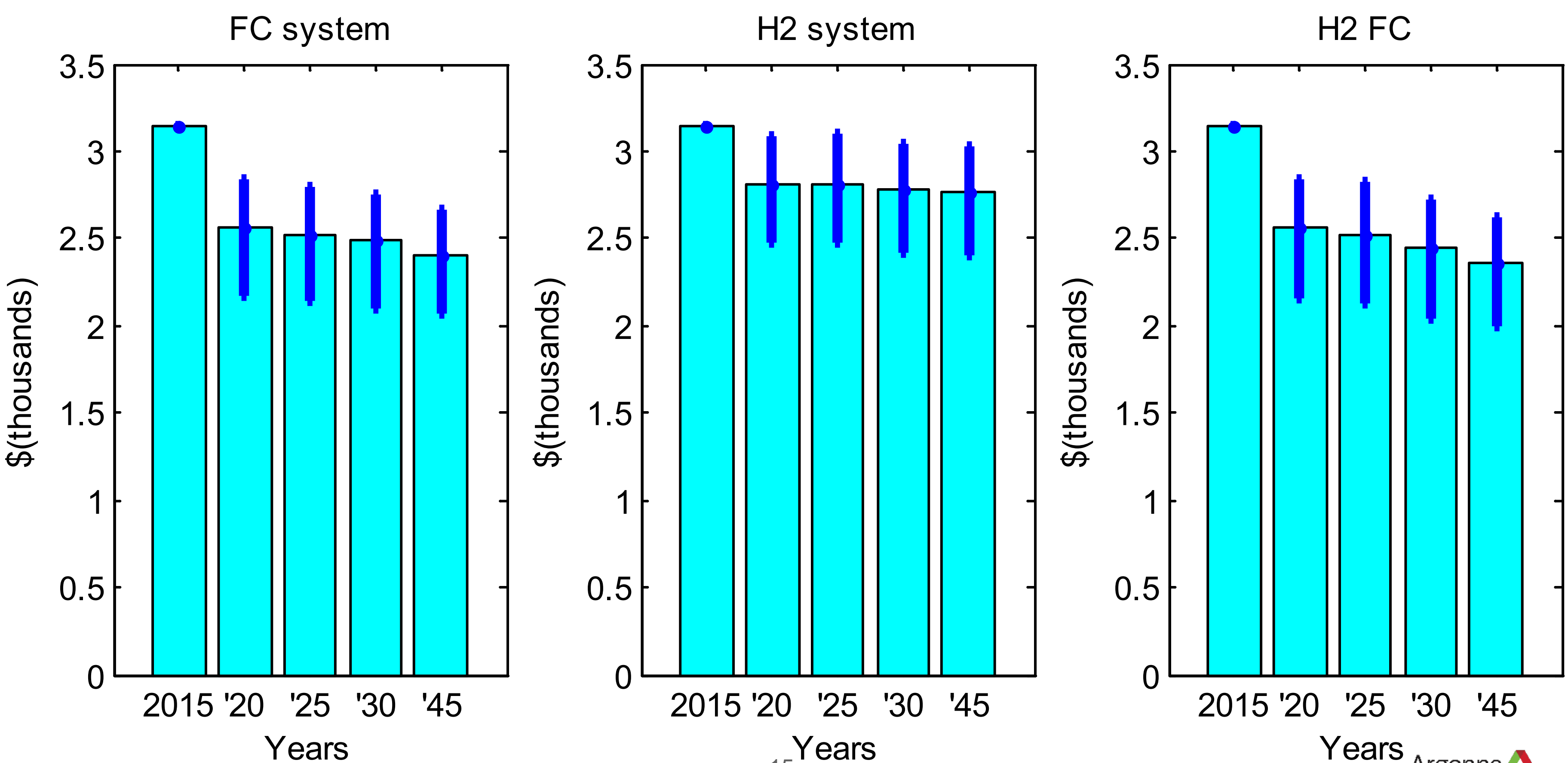
*preliminary results, under review

Technical Accomplishments
Hydrogen Storage Cost

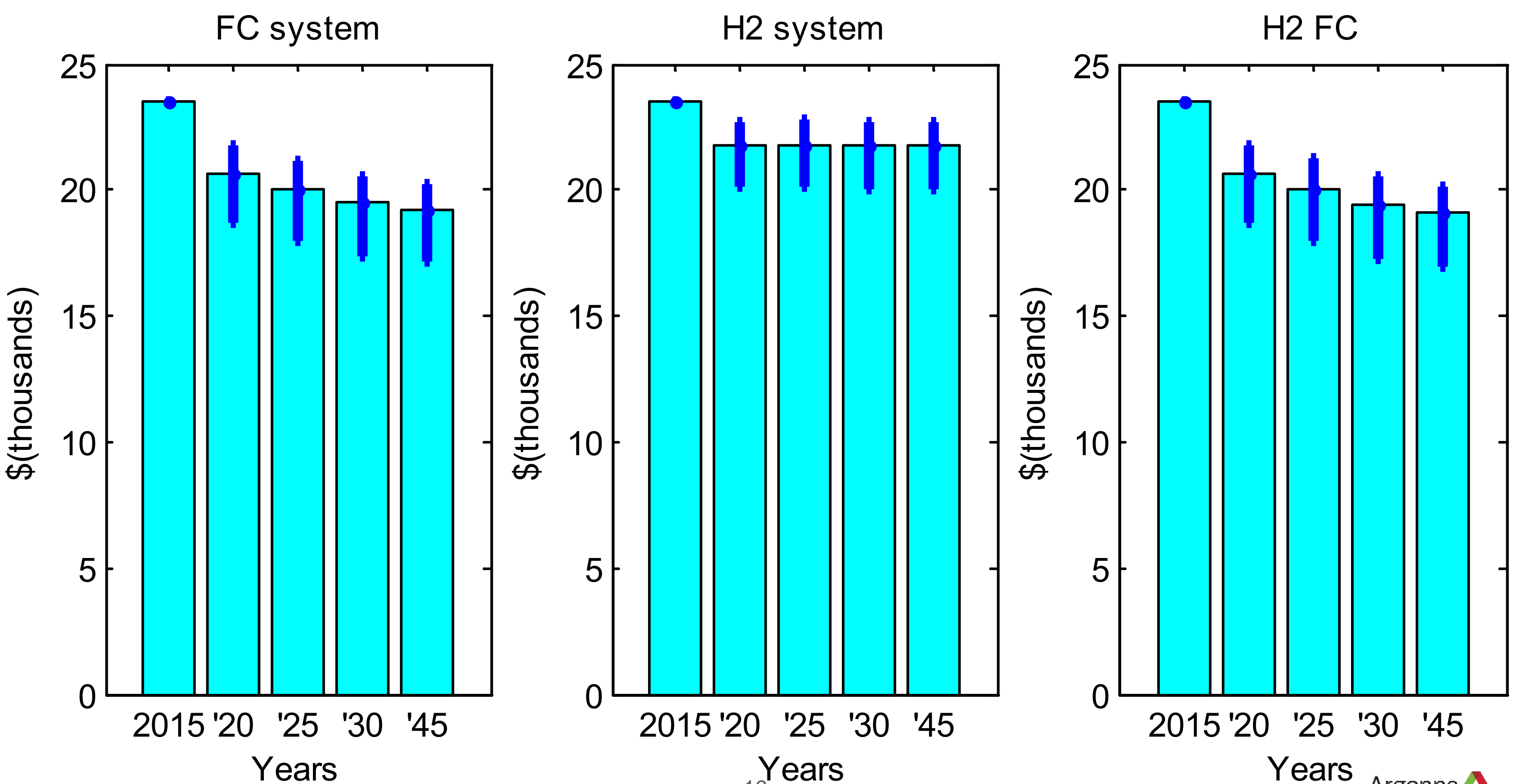
- Hydrogen storage cost could decrease by 20%, due to overall fuel cell system improvements only.
  – Efficient fuel cells will require less hydrogen
  – More usable H_2 per kg of tank will also help reduce the overall cost



*preliminary results, under review

Technical Accomplishments
Fuel Cell Vehicle Cost

- Vehicle cost is impacted by
  - Lower hydrogen tank cost and fuel cell system cost in future years
  - Lower weight & Improved efficiency too results in reduction in component cost



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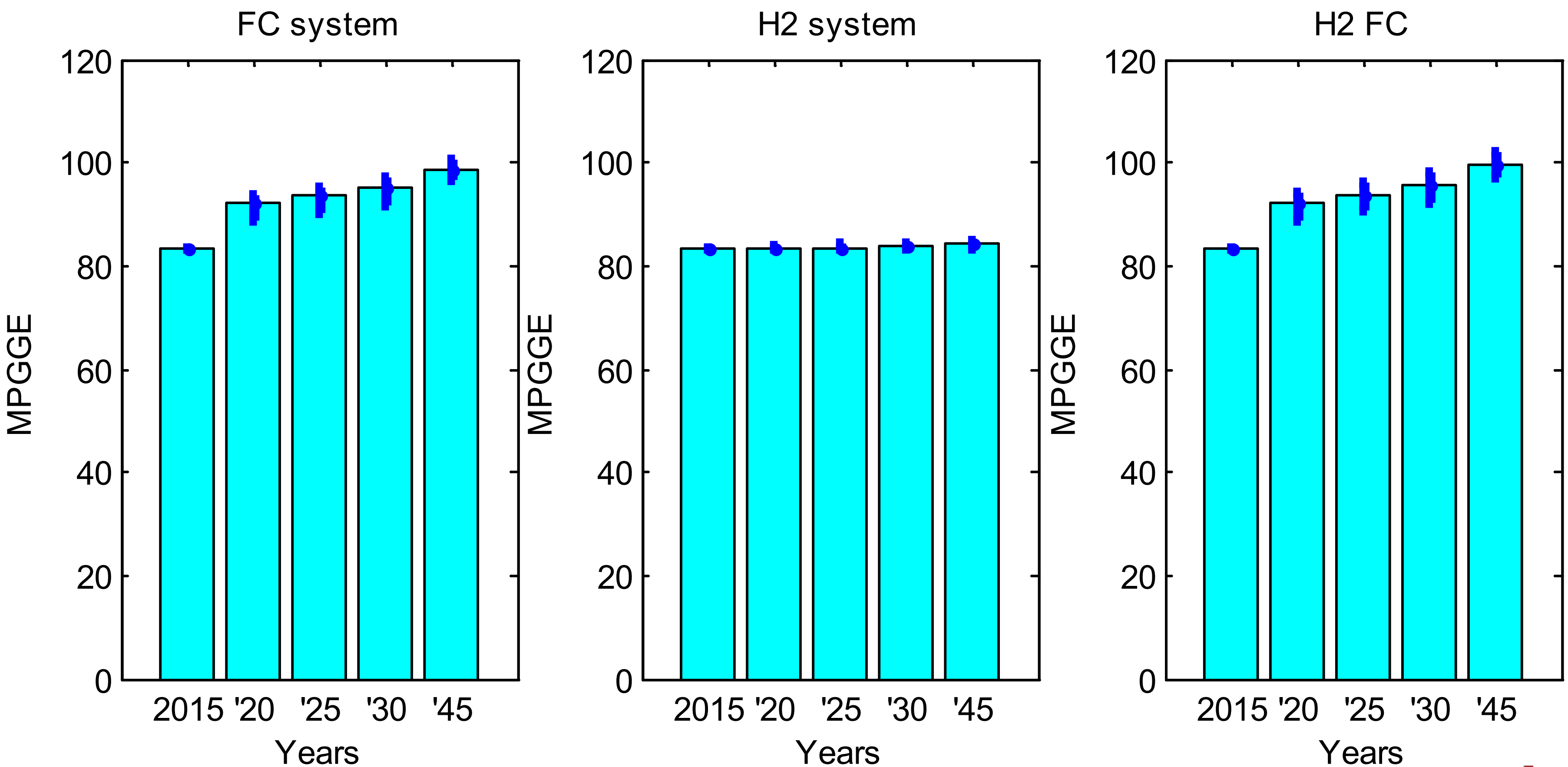
Technical Accomplishments
FCEV Fuel Economy

- Fuel cell system improvement leads to significant fuel savings on the EPA combined driving procedure



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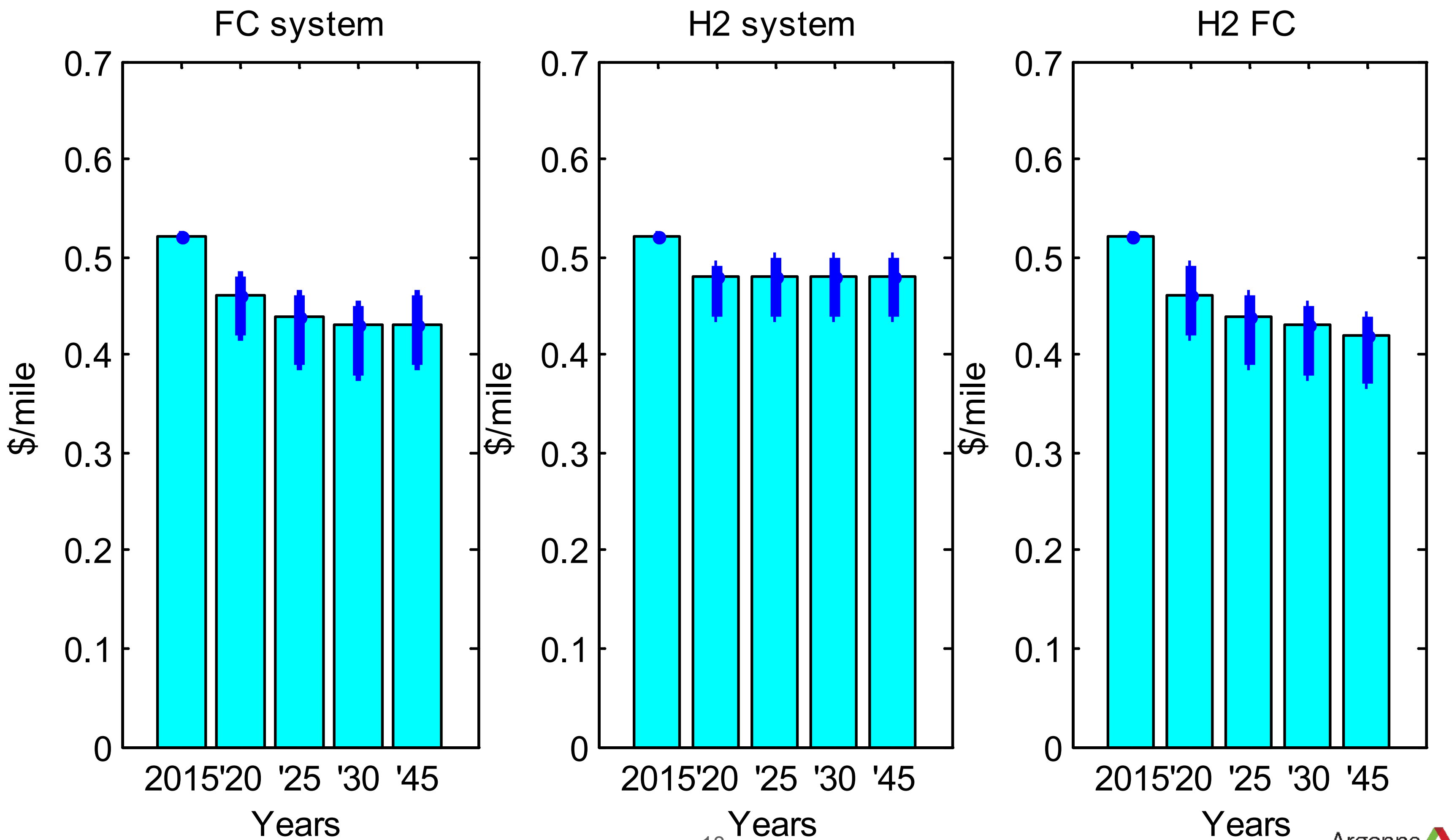
*preliminary results, under review

Technical Accomplishments
FCEV Lifecycle Cost

- The lifecycle cost decrease is mostly due to both fuel cell system and hydrogen storage technologies improvement.

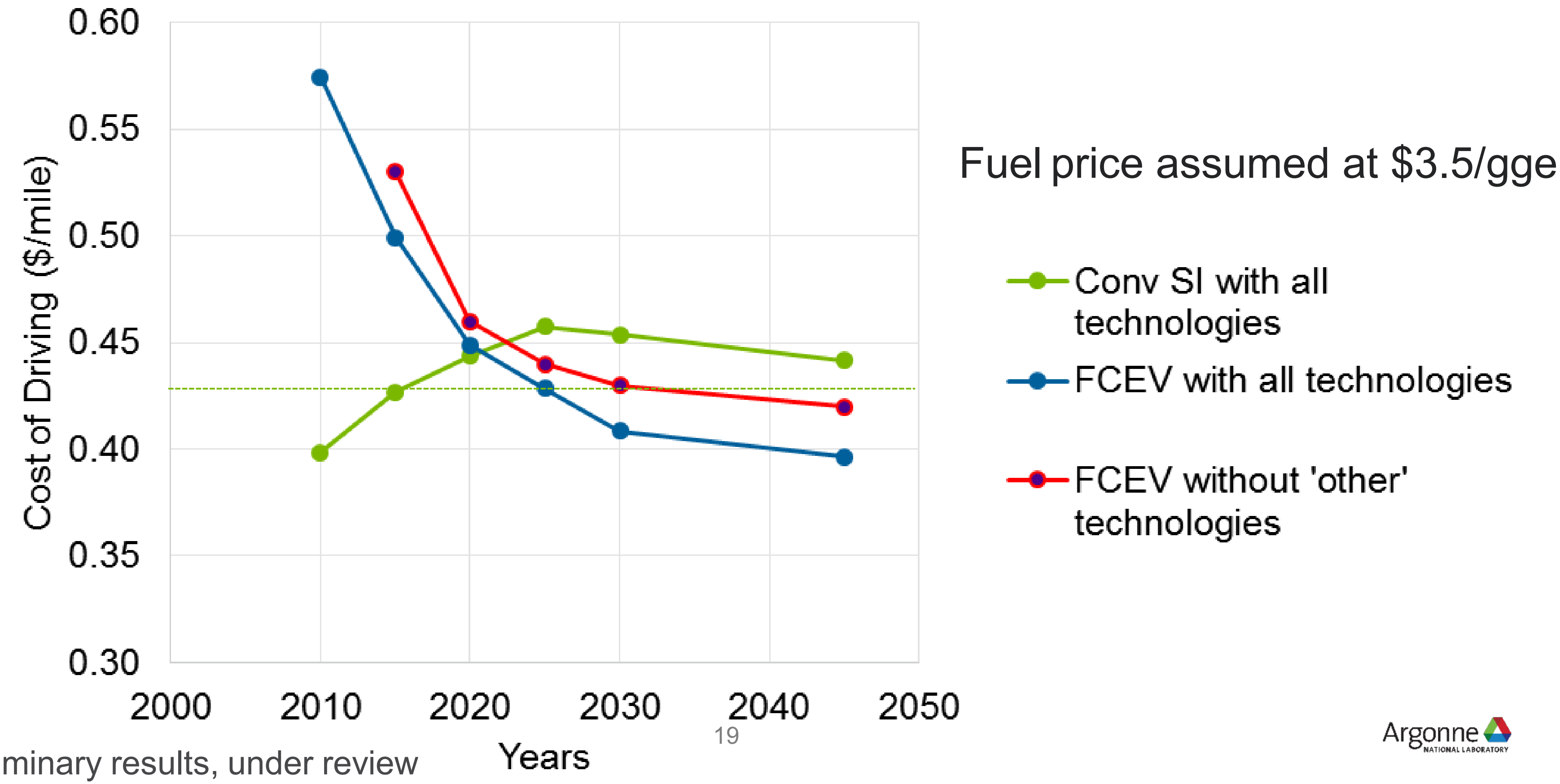


*preliminary results, under review

Technical Accomplishments

FCEVs are Commercially Viable when Achieving Fuel Cell Program Targets

- 2015 Conventional vehicle costs about 43¢/mile.
- Achieving FC program targets makes FCEVs cost competitive by 2030
- Achieving 'all technology' targets, makes FCEVs competitive by 2025



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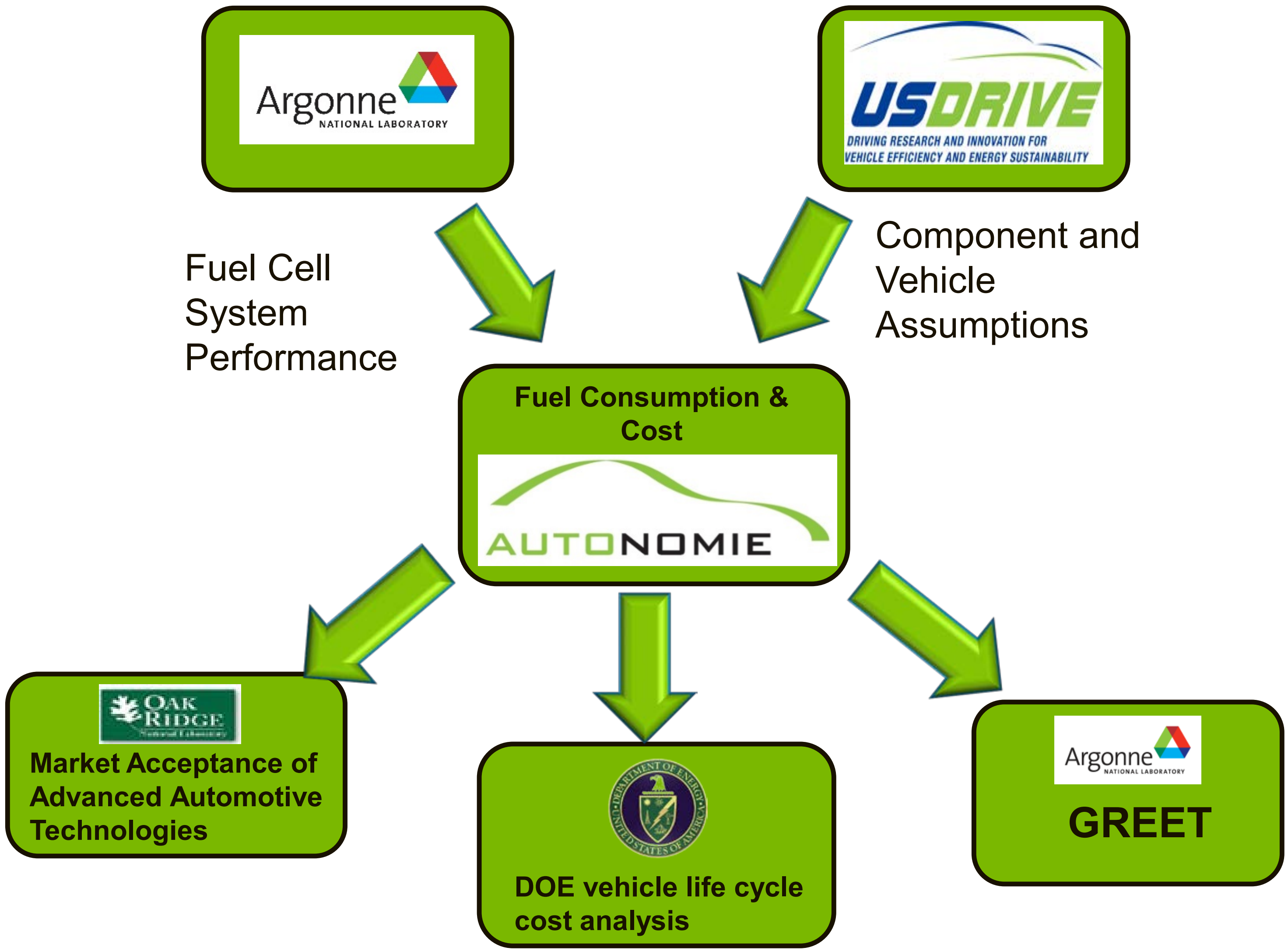
Collaboration and Coordination with Other Institutions



Summary

- Vehicle simulations were carried out to evaluate the benefits of fuel cells and storage without considering improvements in other technologies
- For FCEVs
  - Manufacturing cost will decrease mostly due to the decrease in both fuel cell system and hydrogen tank cost.
  - While better batteries, electric machine and light weighting help, but fuel cell system improvement is the main contributor to fuel savings on the EPA combined driving procedure.
- For a midsize sedan, as fuel cell technologies improves in the future,
  - FC power requirement reduces from 85kW to 82kW
  - Onboard H_2 requirement reduces from 5.5kg to 4.5kg

TECHNICAL BACKUP SLIDES

LCOD Assumptions

Levelized cost includes vehicle and fuel purchase

- Vehicle purchase price estimated from component manufacturing costs and retail price equivalent - RPE factor (1.5)
- Fuel includes liquid, gaseous fuels and electricity
  - Gasoline ($3.5/gallon), Hydrogen ($3.5/gge), Electricity (11¢/kWh)
- Other costs (maintenance, depreciation, insurance, fees, etc.) are assumed to be similar across vehicle types.
- Present Value is determined with a discount rate (7%)
- Levelized cost is the ratio of the present value of the vehicle and fuel costs to the miles driven (14529 miles/year) in N (5) years

$$LC = \frac{PV(P_V + C_{Fi})}{\sum_i^N VMT_i}$$

$$LC = \frac{P_V + PV(C_{Fi})}{\sum_i^N VMT_i}$$

PV = present value

P_V = purchase price of vehicle

C_{Fi} = cost of fuel in year i

VMT_i = vehicle miles traveled in year i

N = Time horizon, years