Project ID # SA044

Cost Benefits Analysis of Technology Improvements in Medium & Heavy Duty Fuel Cell Vehicles

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Project Overview

Timeline	Barriers
• Project start date : Oct 2018 • Project end date : Sept 2019 • Percent complete : 50%	• Lack of Fuel Cell Electric Vehicle and Fuel Cell Bus Performance and Durability Data (A) • Lack of Data on Fuel Cells in Real-World Operation (B) • Hydrogen Storage (C) http://energy.gov/sites/prod/files/2015/06/f23/fcto_myrdd_tech_valid.pdf
Budget	**Partners**
• FY19 Funding : $40k • Percent spent : 50%	• Argonne Fuel Cell Team

Objectives & Relevance

- What are the benefits of fuel cell electric trucks (FCETs)?
  - *Quantify FCETs benefits compared to other powertrains*

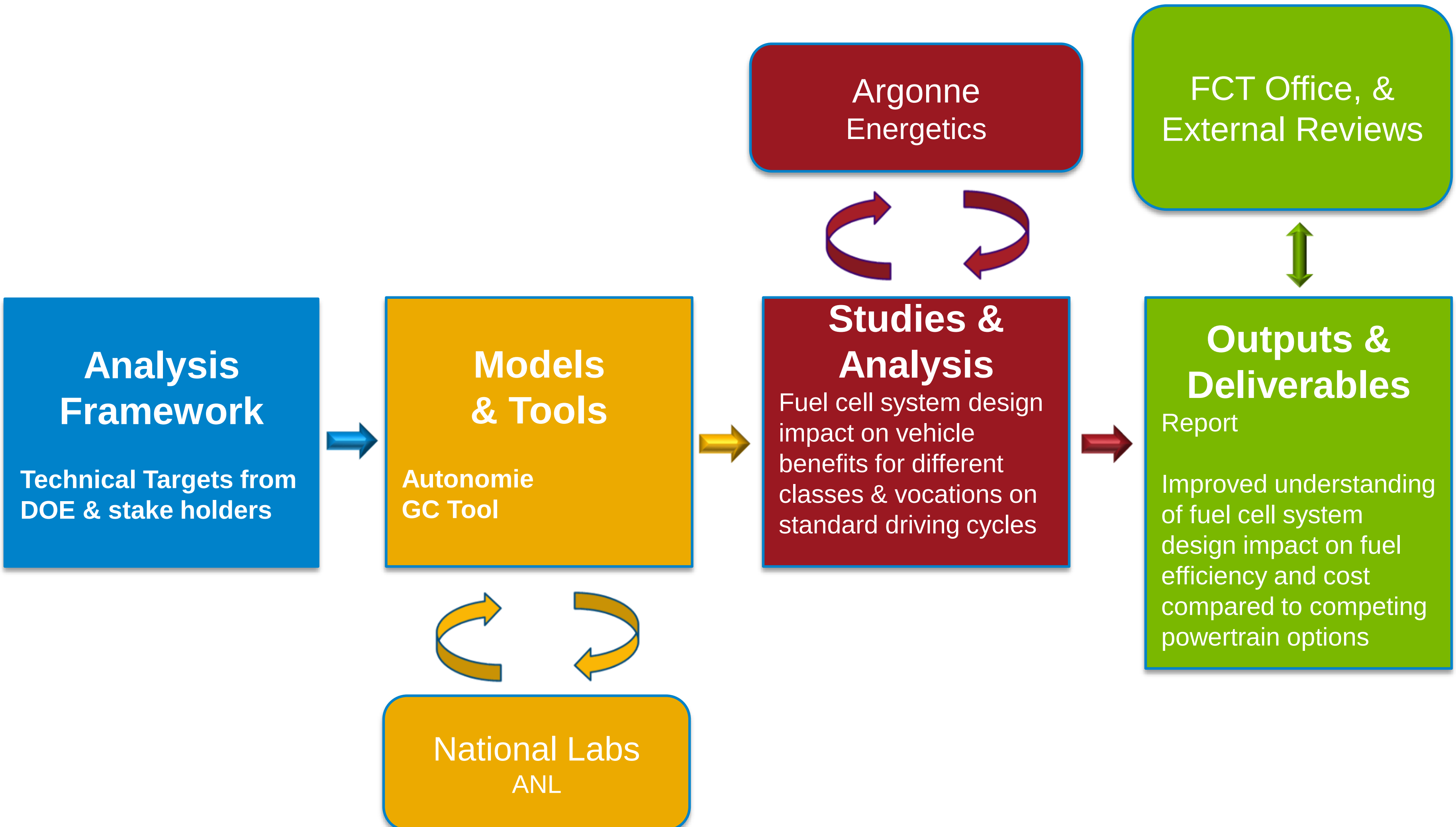
- What are the impacts of meeting the targets?
  - *Develop scenarios for technology improvements, Business as usual & DOE/VTO/FCTO targets*

- What is the impact of FCTO targets on the fuel weight, power, cost of various components?
  - *Size vehicles for comparable performance & examine component requirements*

- What is the point of diminishing returns for technology improvements?
  - *Evaluate how technology improvements in FCETs & other powertrains will affect economic viability*
    - *Compare fuel economy (mpgde)*
    - *Compare total cost of ownership (TCO)*

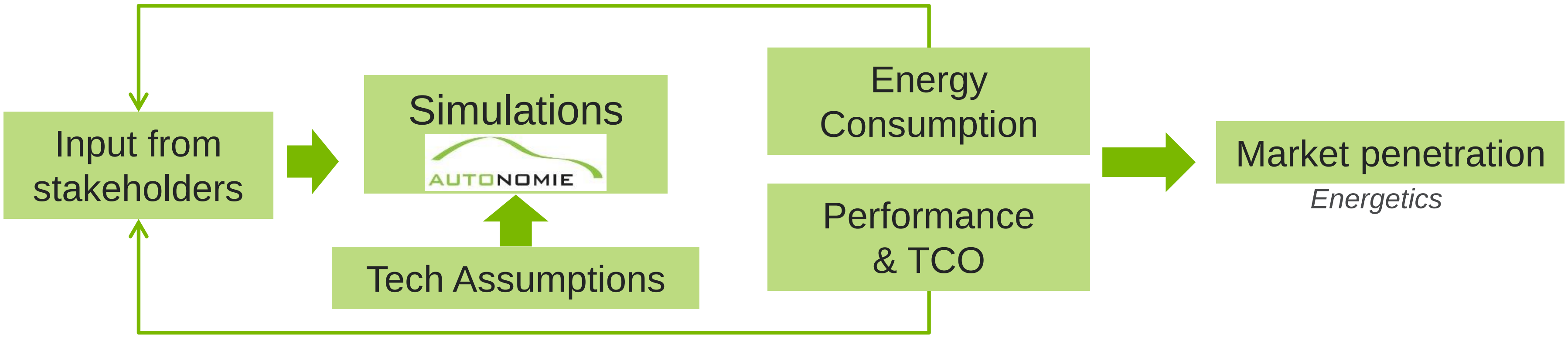
Approach

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

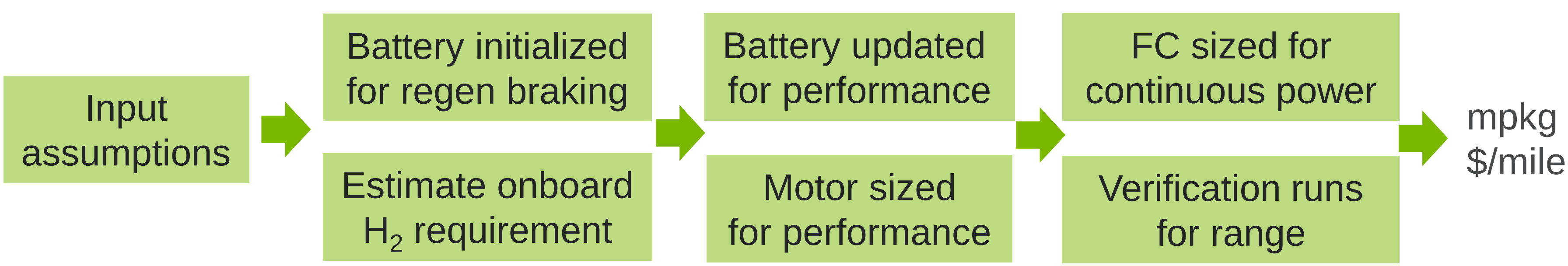


Approach

Size FCETs using assumptions developed through DOE & industry interactions



- Additional DOE activities supported this process: sizing procedure and TCO calculation developed under TV032,TV150,VAN023.
- This work supports FC target setting activities presented in TA024



Vehicle & Powertrain Assumptions

- **Reference technology**: Comparable to 2017-18 trucks. Simulated per regulatory load conditions on ARB Transient, EPA 55 & EPA65 cycles
- All powertrain variants are sized for similar performance capability

Performance requirements	Class 4 Delivery	Class 6 Delivery	Class 8 Sleeper	Class 8 Day Cab	Class 8 Vocational
Cargo (kg)	2,590	5,091	17,273	17,273	6,818
6% grade speed (mph)	50	37	32	31	28
Cruise speed (mph)	70	70	65	65	60
Acceleration 0-30mph (s)	9	14	18	18	18
Acceleration 0-60mph (s)	30	50	60	66	66

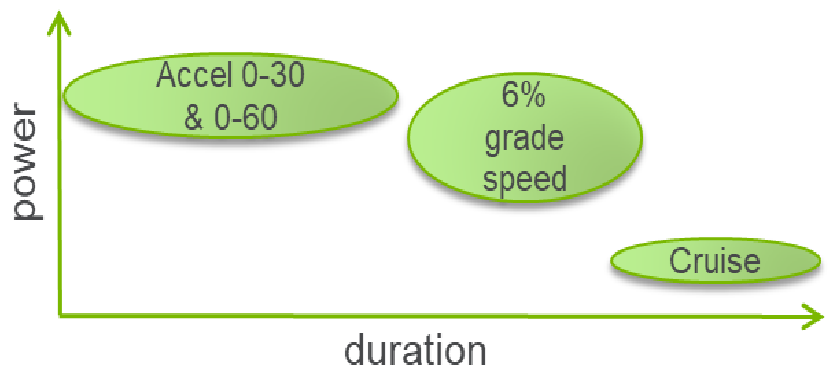
- **Additional Powertrain Considered**
  - Conventional
  - Start-stop (ISG)
  - Hybrid (HEV)
  - Series plug in hybrid (PHEV)
  - Battery electric vehicles (BEV)

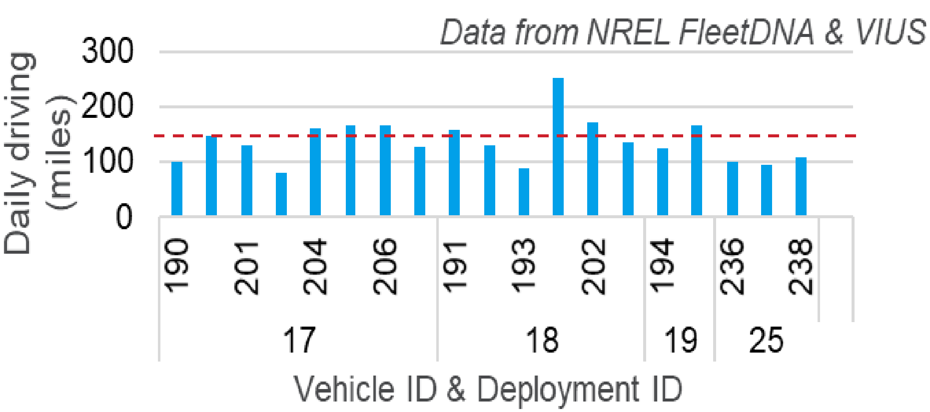
Conv and HEVs are diesel powered. CNG variants will be added later

Performance Based Sizing Ensures Fair Comparison

Sizing Assumptions

- No trade off on payload or performance
  - Fixed payload across all powertrains
  - Match or better conventional vehicles performance
- BEVs range depend on the application.
  – Fleet DNA, VIUS are used as reference for range.
- PHEVs sized for 50% of BEV electric range.





As performance parameters are not widely published for heavy vehicles, the baseline values have been estimated through simulations.

Technology Progress Assumptions

- Interim & ultimate targets expected to be achieved by 2030 and 2050 respectively.
- Additional vehicle technologies will also improve.
  - >30% reduction for Cd, Cr & glider weight
- Competing vehicles will be more efficient
  - Eg. 59% diesel engine efficiency target for 2050
- Two technology progress cases are considered to account for uncertainties.

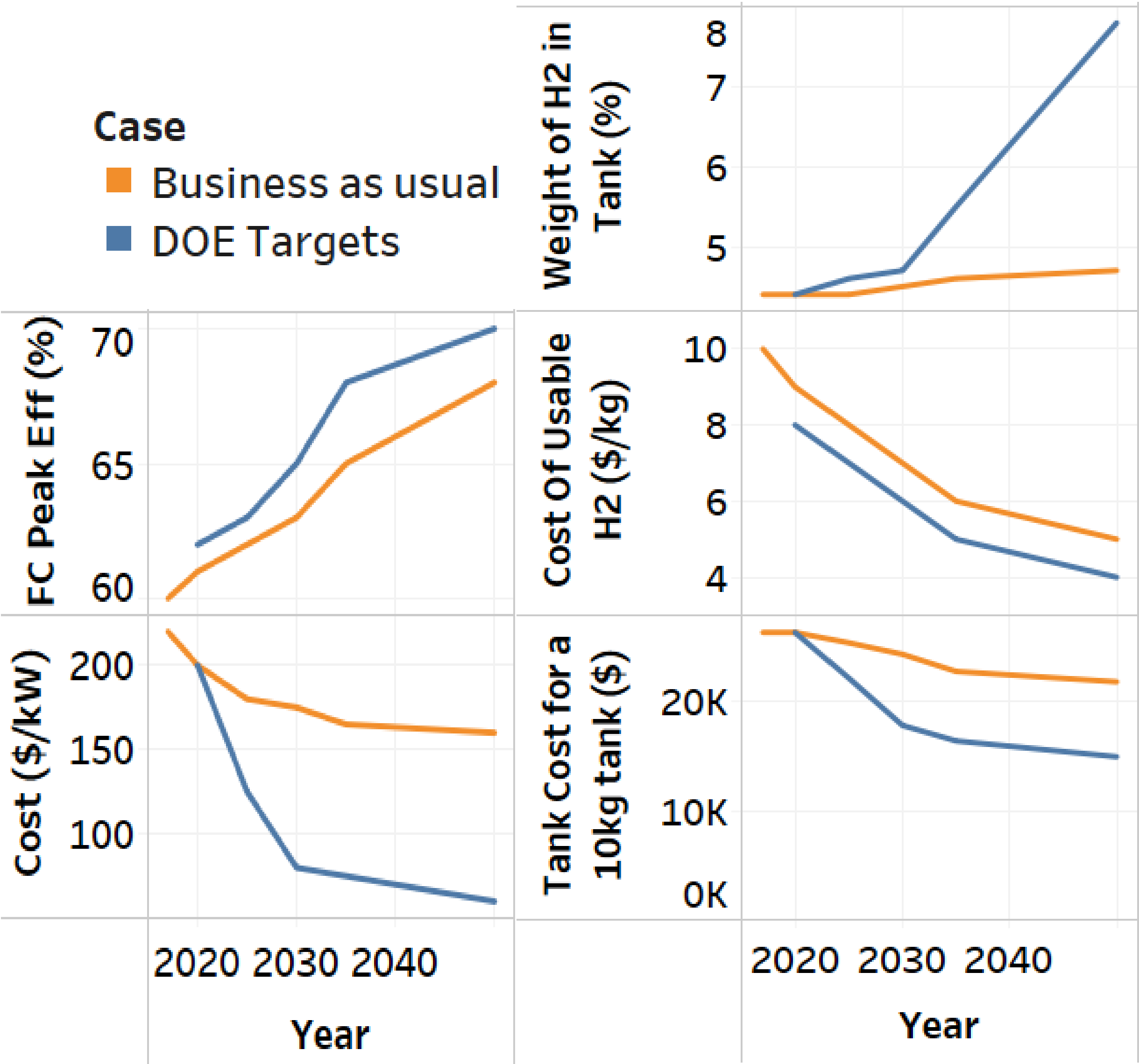


Table is provided in backup slides

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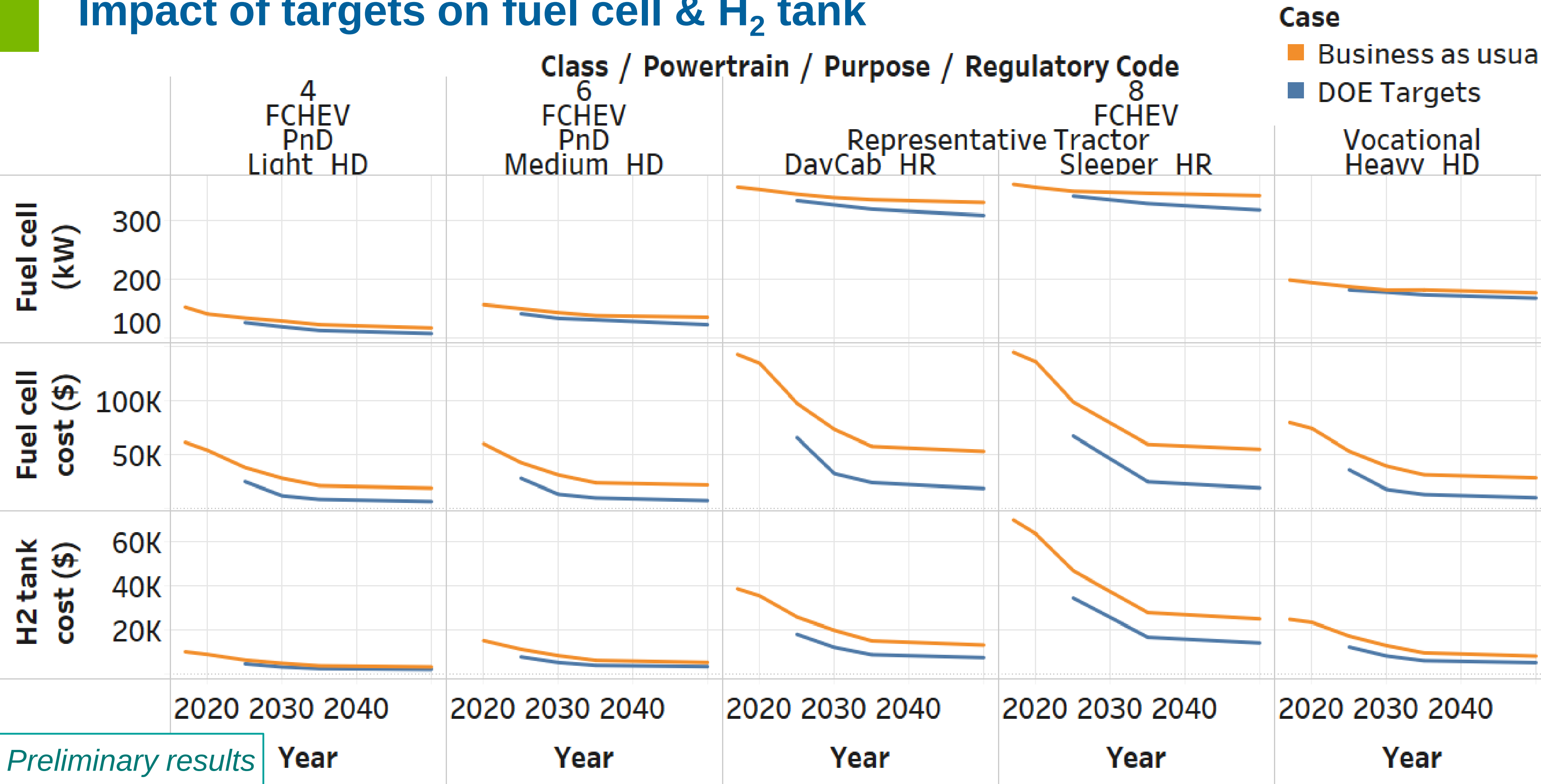
Technical Accomplishments

Impact of targets on fuel cell & H_2 tank

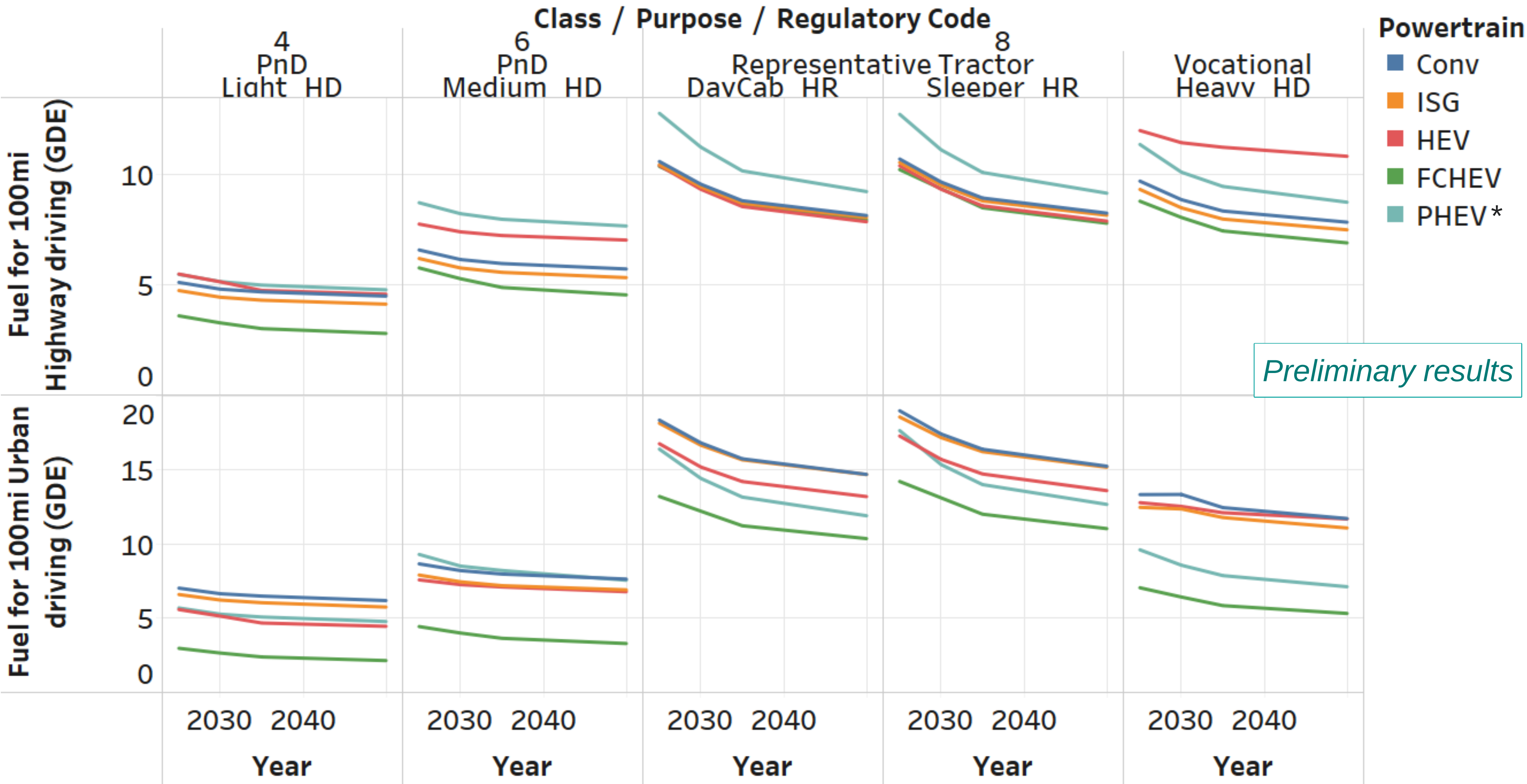


Preliminary results

- Grade climbing requirement dictates fuel cell power for FCETs. Weight reduction helps reduce the power requirements.
- Cost targets have a more appreciable impact in reducing system cost

Technical Accomplishments

Fuel consumption comparison across various powertrains

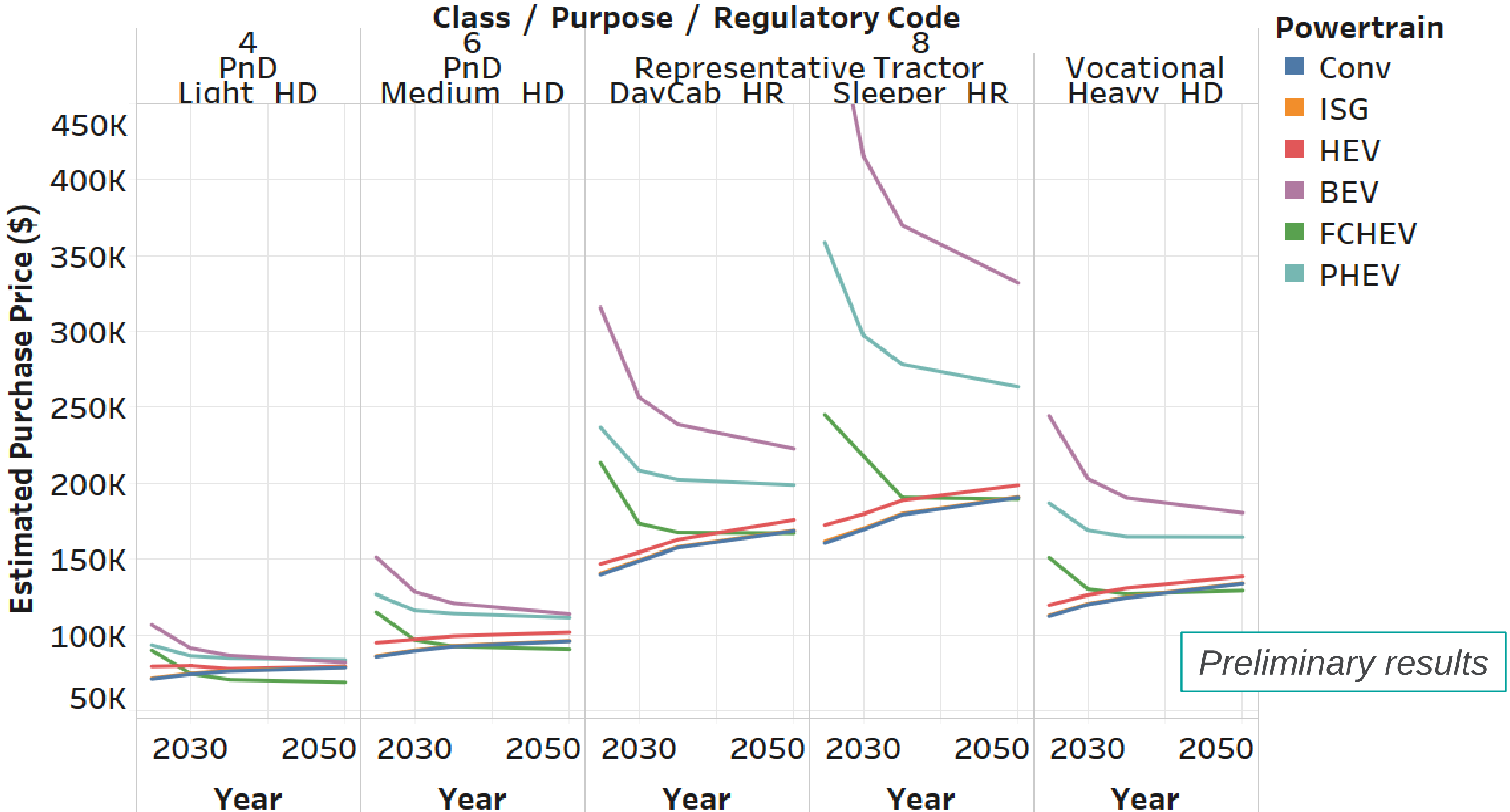


- FCETs are most beneficial for Urban driving scenarios
- Class 8 Sleepers are already very efficient for highway driving.

* Charge sustaining operation is shown for PHEV.

Technical Accomplishments

Truck purchase price comparison across powertrains

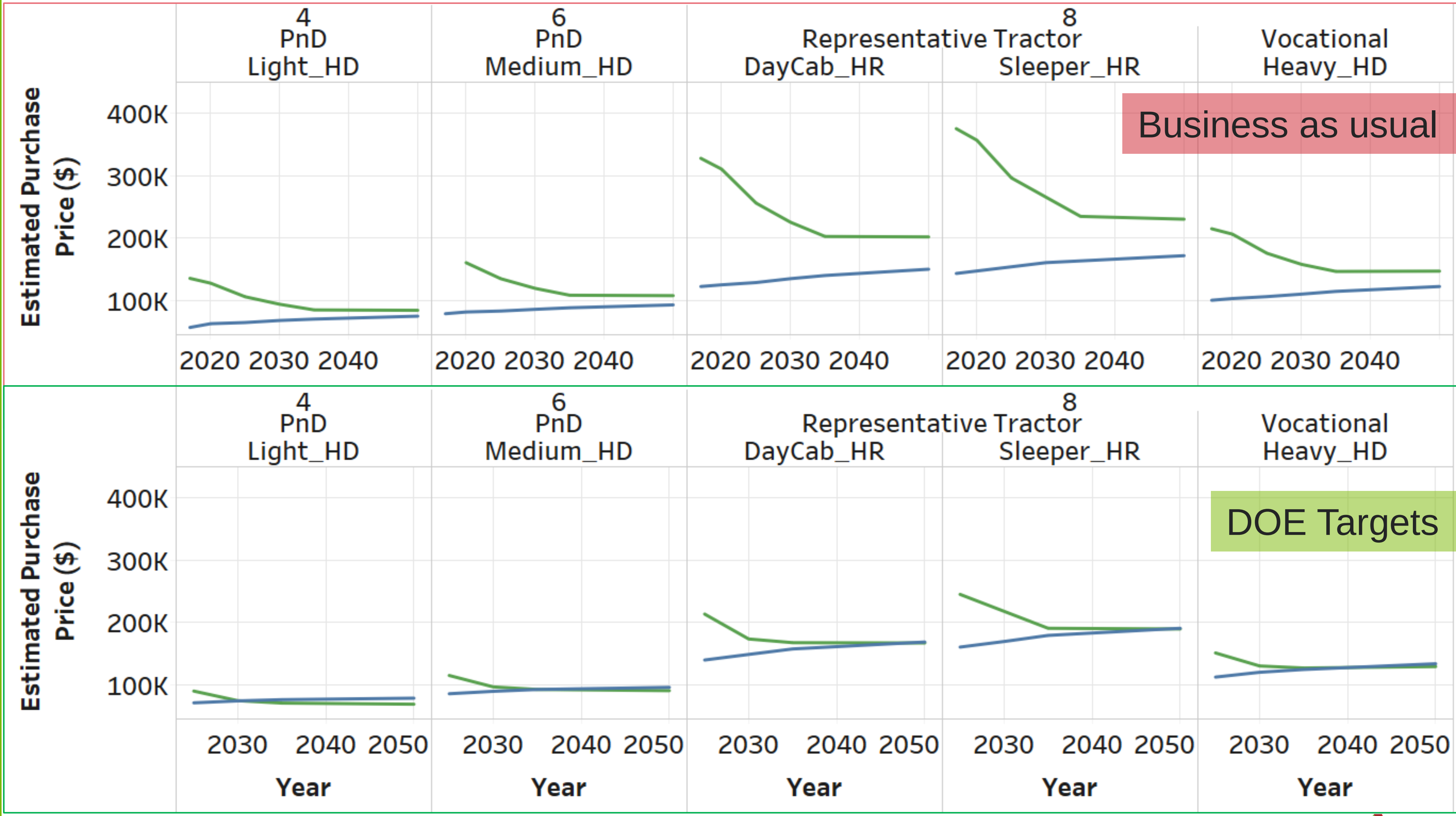


- Battery and FC system costs are expected to drop. Engine cost will increase due to stricter emission norms and cost of improving efficiency.

* All powertrains are simulated with same body & glider properties as that of conventional truck

Technical Accomplishments

If DOE targets are not met, none of the truck segments evaluated in this case will achieve cost parity with diesel by 2050



Preliminary results

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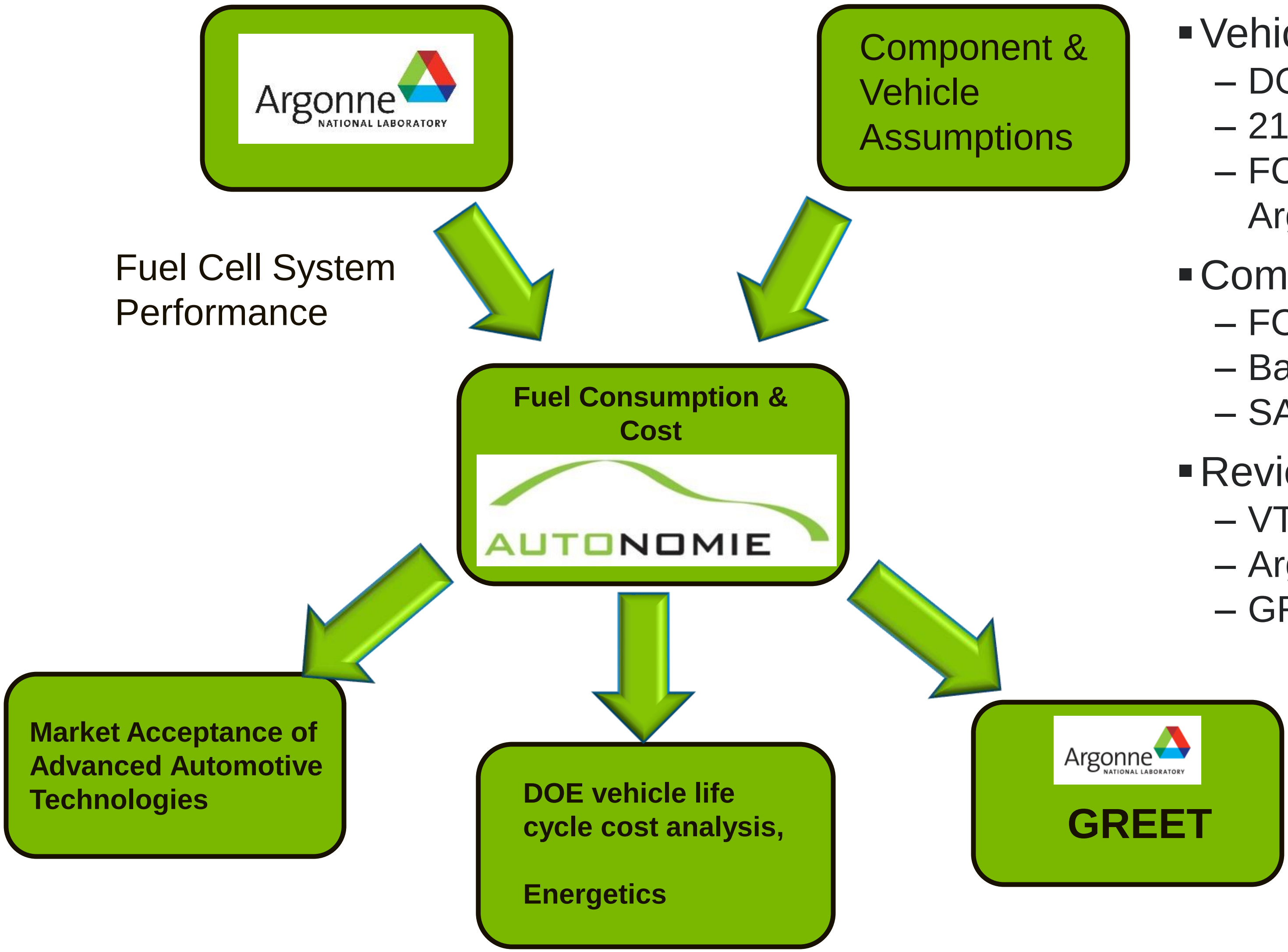
Collaboration and Coordination with Other Institutions



- Vehicle Assumptions
  - DOE VTO
  - 21CTP partners
  - FC Workshop @ Argonne
- Components
  - FCTO
  - Ballard
  - SA Inc
- Reviews
  - VTO & FCTO
  - Argonne FC team
  - GREET team

Proposed Future Work

- Provide information to estimate market penetration
  - Fuel consumption & vehicle cost estimates

- Expand the analysis to include TCO ($/mile) to conduct techno-economic impact
  - When will FCETs achieve cost parity with diesels?
  - Which vocations will first achieve cost parity with current technology targets?

- Evaluate TCO sensitivity to changes in Fuel Cell & Storage technologies
  - Similar analysis was performed for light duty vehicles in FY18

- Add more vehicle types to this analysis, include real world conditions to estimate operating costs

Summary

- What are the benefits of fuel cell electric trucks (FCETs)?
  - *FCETs demonstrated over 50% fuel savings in urban driving scenario.*
  - *Conventional Class 8 Sleeper trucks are the toughest competition for FCETs*

- What are the impacts of meeting the targets?
  - *FCETs can achieve cost parity with diesel trucks only if the targets are met.*
  - *Fuel cost parity and fuel availability are other considerations affecting consumer acceptance*

- What is the impact of FCTO targets on the fuel weight, power, cost of various components?
  - *Power requirements will reduce marginally due to light weighting.*
  - *Cost targets play a critical role in reducing overall ownership costs*

- What is the point of diminishing returns for technology improvements?
  - *TCO comparison will be analyzed next*

Backup Slides

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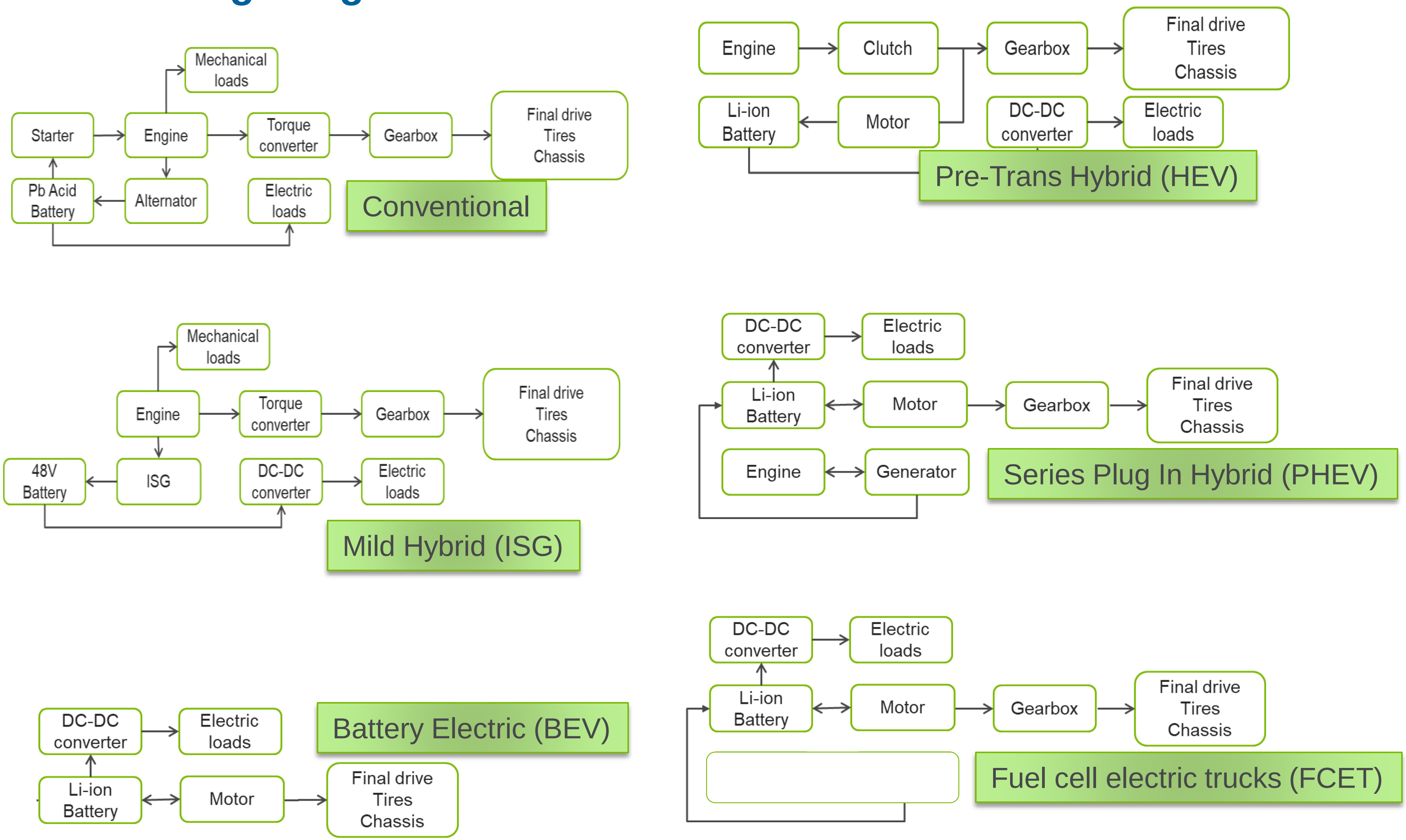
Architectures considered in this study

Each powertrain has its own sizing logic.
This is being integrated to AMBER



Acronyms

Acronym	Description
MD HD	Medium Duty & Heavy Duty
FCET	Fuel cell electric truck
FCHEV	Fuel cell hybrid electric vehicle
Light_HD	EPA uses this terms to denote Class 3-4 vehicles
Medium_HD	EPA uses this terms to denote Class 5-6 vehicles
Sleeper_HR	HR stands for high roof configuration. Mid and low roof designs are other variants
mpgde	Miles per gallon diesel equivalent.
ARB Transient	Regulatory transient driving cycle used by EPA
EPA 55, EPA 65	55mph and 65mph regulatory cycles used by EPA
TCO	Total Cost of Ownership
PnD	Pickup and Delivery

FC & H_2 Assumptions

- The ‘Low’ assumptions refer to the Business as Usual scenario. ‘High’ case reflects the impact of DOE funding.

- An excel sheet with all assumptions (across all powertrains and components) was shared with DOE earlier.
- It will be available from Argonne website by end of FY19.

Year	Case	FC Peak Eff (%)	FC specific power (W/kg)	FC cost ($/kw)	H_2 in 100kg tank (kg)	Tank variable cost ($/usable H_2)	Tank fixed cost ($)	Cost of Usable H_2 ($/kg)
2017	Low	0.6	650	220	4.4	428	983	10
2020	Low	0.61	650	200	4.4	428	983	9
2020	High	0.62	650	200	4.4	428	983	8
2025	Low	0.62	650	180	4.4	415	923	8
2025	High	0.63	650	125	4.6	350	923	7
2030	Low	0.63	659	175	4.5	400	863	7
2030	High	0.65	710	80	4.7	300	559	6
2035	Low	0.65	659	165	4.6	390	649	6
2035	High	0.68	740	75	5.5	280	476	5
2050	Low	0.68	670	160	4.7	380	559	5
2050	High	0.7	870	60	7.8	266	326	4

Sizing process:

All trucks are based on popular production vehicles.

1. Representative Trucks
- Based on market data.
- Vehicle data is from OEMs & other sources

2. Develop Baseline Model
- Determine performance capabilities and fuel economy

3. FCET Sizing
- Determine component sizes to meet performance
- H_2 requirement

4. Simulate Truck Performance
- Verify performance
- Verify range
- Verify real world usage

Sizing process was developed in prior work (TV032)

- Argonne has developed models for over 20 class vocation combinations
  - Simulation models and assumptions are available to support any DOE funded activity.

Cost estimation process:

- Developed under a VTO's VAN023 project.
  - Retail price of trucks were collected from dealers and OEMs.
  - 20% margin is assumed to estimate the cost of manufacturing the truck
  - Cost of mature components such as engine & transmission are computed based on the mass of those components.
    - There is additional cost assumed for improvement in efficiency.
    - All these assumptions and cost calculations will be made available in a detailed report by end of FY19

- MD&HD components with new technologies are assumed to have an additional cost multiplication factor during the initial years.

Year	Engine	Light weighting	Motor	Battery	Fuel cell	H2 tank
2017	1.24	1.13	1.63	1.82	1.82	1.82
2020	1.24	1.13	1.63	1.82	1.82	1.82
2025	1.10	1.05	1.29	1.47	1.47	1.47
2030	1.00	1.00	1.08	1.23	1.23	1.23
2035	1.00	1.00	1.00	1.00	1.00	1.00
2050	1.00	1.00	1.00	1.00	1.00	1.00