# Market Segmentation Analysis of Medium and Heavy Duty Trucks with a Fuel Cell Emphasis

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## *Overview:*
# Fuel Cell M/HD Vehicle Market Segmentation

| Timeline | Barriers (4.5) |
|---|---|
| Start: September, 2017<br>End: September, 2018<br><br>35% complete | **A. Future Market Behavior**<br>• Assessing competitiveness of fuel cell M/HDVs<br>**C. Inconsistent Data, Assumptions & Guidelines**<br>• Consistent modeling methodology using established cost/price targets<br>**D. Insufficient Suite of Models and Tools**<br>• Update powertrain optimization models for M/HDVs and expand the national stock model |
| **Budget** | **Partners** |
| Total Project Funding: $150k<br><br>• FY18: $150k<br><br>Total DOE funds received to date: $150k | **University of Vanderbilt – *Modeling***<br>• Dr. Yuche Chen<br><br>**Cummins, Toyota, FedEx, Nikola – *Peer Reviewers*** |

# *Relevance (1/2):* FCTO Systems Analysis Framework

**Fuel Cell M/HDV Market Segmentation Integrates System Analysis Framework:**

- Leveraging and expanding existing systems analysis models
- Systems analysis approach using established cost and price targets

- H2@Scale
- VTO/BETO/FCTO Market Segmentation
- TCO Frameworks

- Fuel Cell Technologies Office
- Fuel cell vehicle analysis community
- Industry stakeholders

**Analysis Framework**
- Cost estimation (TCO)
- Stock modeling
- Energy resource utilization
- $H_2$ supply-chain optimization

**Models & Tools**
- FASTSim
- SERA
- VISION
- H2A production and delivery models

**Studies & Analysis**
- Fuel cell M/HDV market analysis
- Framework implementation

**Outputs & Deliverables**
- Reports
- Public insights into market potential

- FCTO Program Targets
- GPRA Targets

<u>Acronyms</u>

**FASTSim:** Future Automotive Systems Technology Simulator
**GPRA:** Government Performance and Results Act
**H2A:** Hydrogen Analysis
**M/HDV:** Medium/Heavy-Duty Vehicles
**SERA**: Scenario Evaluation and Regionalization Analysis
**TCO:** Total Cost of Ownership

# *Relevance (2/2):* FCEV Market Segmentation Objectives

**FY18 Objectives:**

1. To provide industry, government, and non-government ***stakeholders*** a broad scoping ***assessment*** of medium/heavy duty fuel cell vehicle ***market opportunities*** across different classes, vocations, regions, and time
2. Assess technical ***barriers and opportunities*** for improvement in the medium/heavy duty fuel cell vehicle technology space to guide DOE ***investment*** in advanced technologies

**The FCEV Market Segmentation project aims to identify the most promising markets for medium/heavy duty vehicles using a systems analysis approach with established technology and cost targets**

# *Approach (1/4):* Analysis Method Integrates Multiple Models

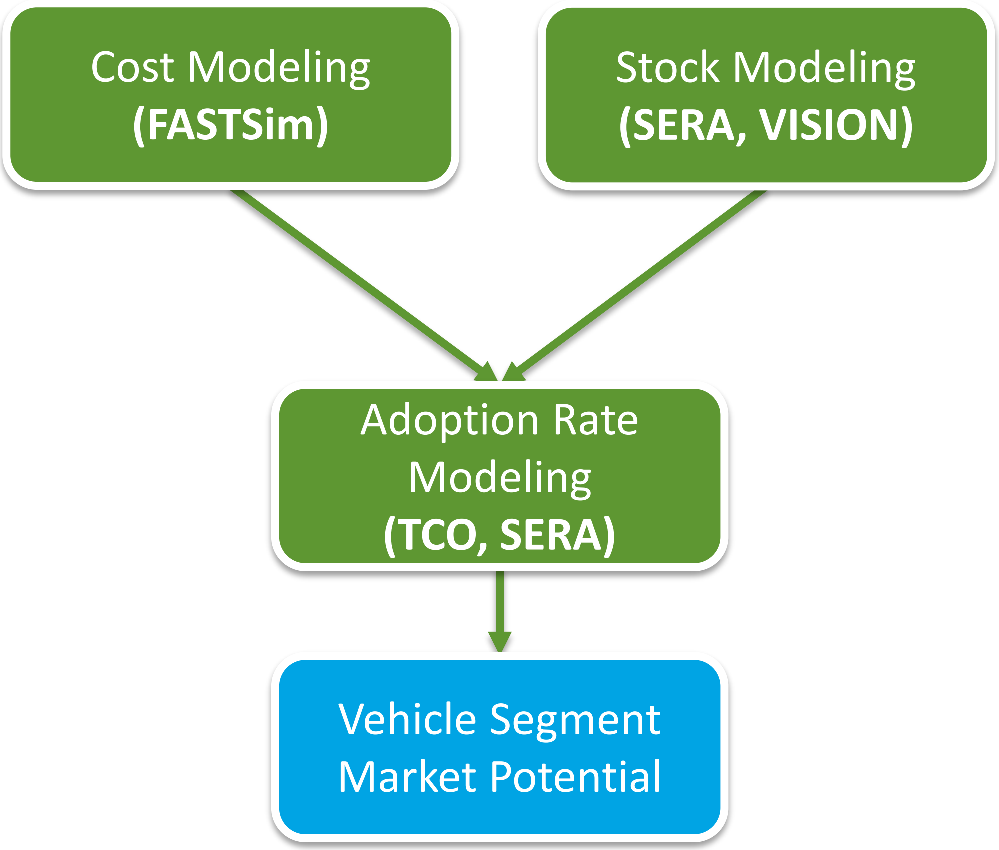
Orange = Data
Green = Model
Blue = Results

**Future Automotive Systems Technology Simulator *(FASTSim)***

- Powertrain cost optimization using vehicle attributes and vocations

**Scenario Evaluation and Regionalization Analysis *(SERA)***

- National stock model based on VISION model, IHS/Polk data
- Stock, VMT, and fuel consumption disaggregated by region, vehicle, vocation, and time
- Total cost of ownership (TCO) analysis using regional-, vehicle-, vocation-, and time-specific detail




**The combination of FASTSim and SERA will allow for geographically explicit stock modeling and fuel cell M/HDV market potentials**

# *Approach (2/4):*
# Powertrain cost optimization using FASTSim

Orange = Data
Green = Model
Blue = Results

**1. Vehicle/Vocation Assessment**

↓ *Vehicles and vocations*

**2. Fleet DNA Drive-Cycle Data**

↓ *Multiple drive-cycles by vocation*

**3. DRIVE**

↓ *Representative drive-cycle for vocation*

**5. FASTSim Cost Optimization** ← **4. Vehicle and Cost Target Data**

↓

***Vehicle Cost***
***Fuel economy***
***Weight***

## FASTSim Cost Modeling Steps

1. Vehicles and vocations determined by market share data
2. Fleet DNA data used to obtain drive-cycle data for each vehicle class/vocation combination
3. The Drive-Cycle Rapid Investigation, Visualization, and Evaluation (DRIVE) tool used to create representative drive-cycles
4. Vehicle attribute and GPRA cost targets (2018/2040) data input
5. Vehicle and vocation drive-cycle data used to optimize vehicle cost

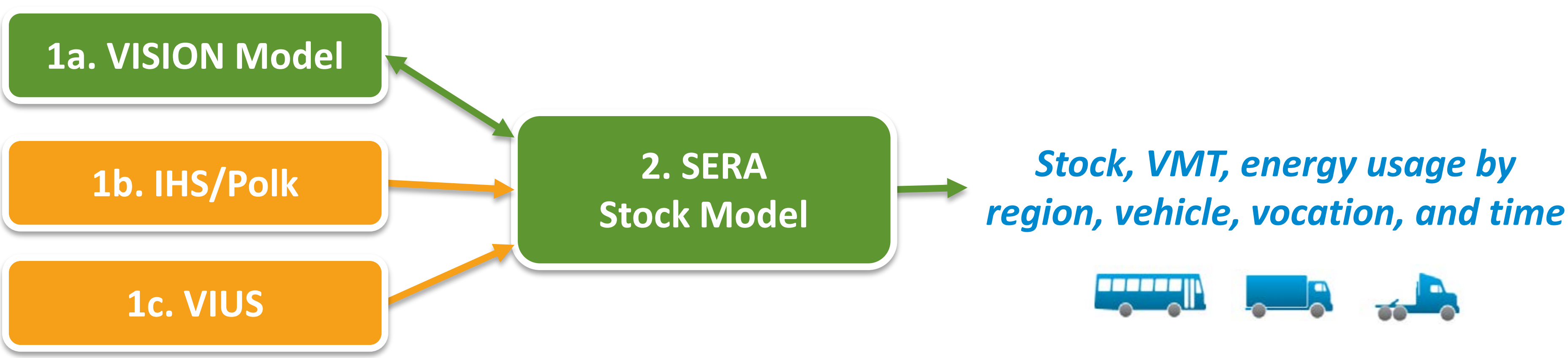
**Vehicle/vocations assessed in FASTSim to determine cost, fuel economy, and weight**

## *Approach (3/4):*
# SERA M/HDV Stock Modeling

**<u>SERA Stock Modeling Steps</u>**

1. Determine data availability across various data sources
   a) VISION Model
      - Historic and future sales and market share by vehicle class and fuel type
      - Annual vehicle-miles-travel (VMT), survival rate, and fuel economy
   b) IHS/Polk
      - Historic sales, market share data by vehicle and vocation
   c) VIUS
      - Historic sales, market share data
      - Annual VMT, fuel efficiency
2. Reconcile data sources, determine which to use
3. Incorporate data into SERA model, iterate until agreement between VISION and SERA

**Develop SERA stock model based on various data sources to track vehicle population, VMT, and energy usage over time and region**



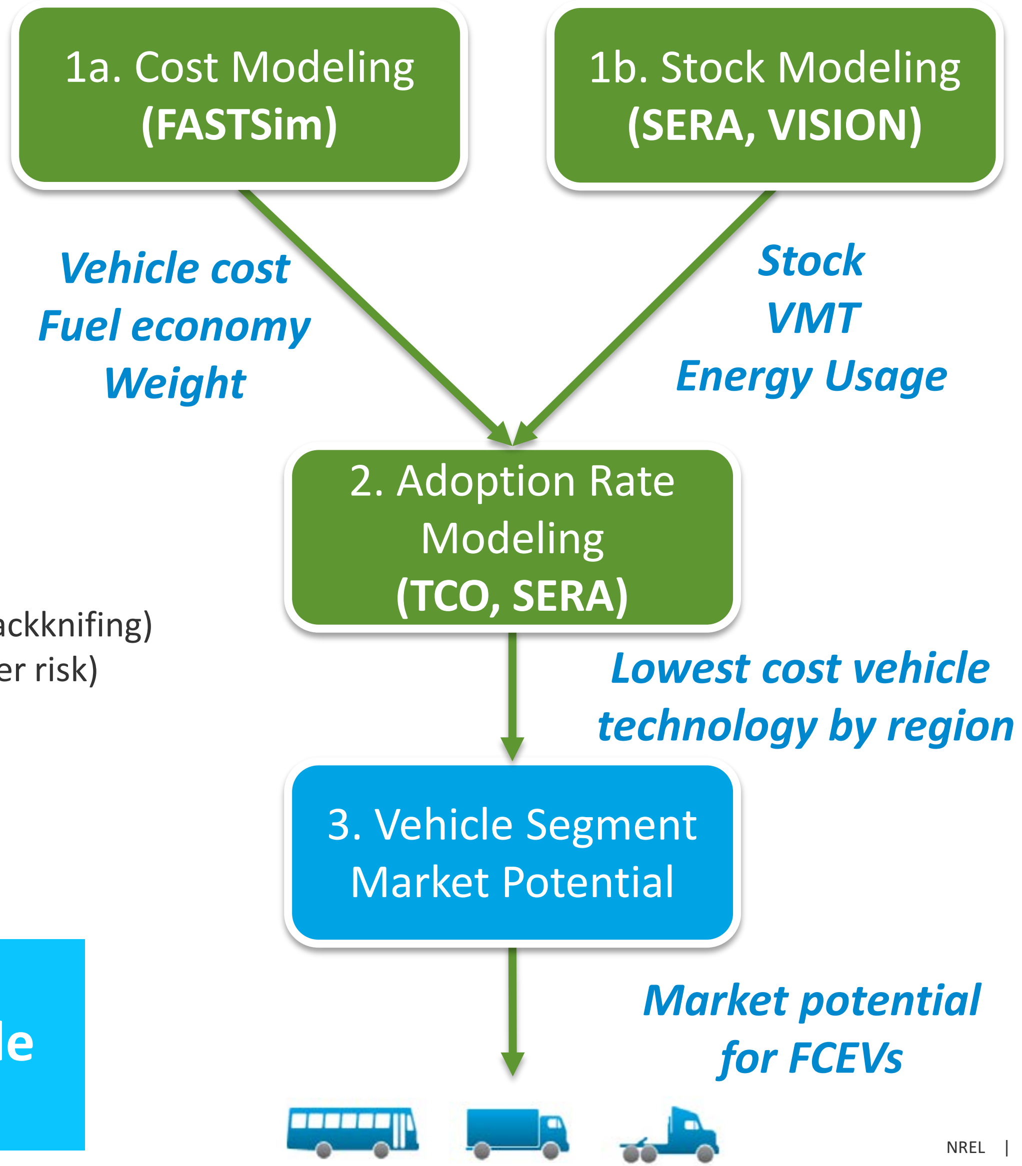
# *Approach (4/4):* Market Share Potential Based on Vehicle TCO

**Total Cost of Ownership (TCO) Modeling**

1. Integrate vehicle cost, fuel economy, and weight (FASTSim outputs) into SERA stock model

2. Incorporate additional ownership costs into SERA stock model
   1. Fuel cost (AEO)
   2. Operating & Maintenance cost
   3. Opportunity Costs (Payload, Utilization)
   4. Other Potential Value Streams
      - A. Independent electric motors (reduced jackknifing)
      - B. Lower center of gravity (reduced roll-over risk)

3. Identify vehicles/vocations with lowest TCO by region. Complete sensitivity analysis




**SERA model will be used to calculated TCO for each vehicle class and vocation by region**

# *Accomplishments and Progress (1/6):* FASTSim: Powertrain cost optimization

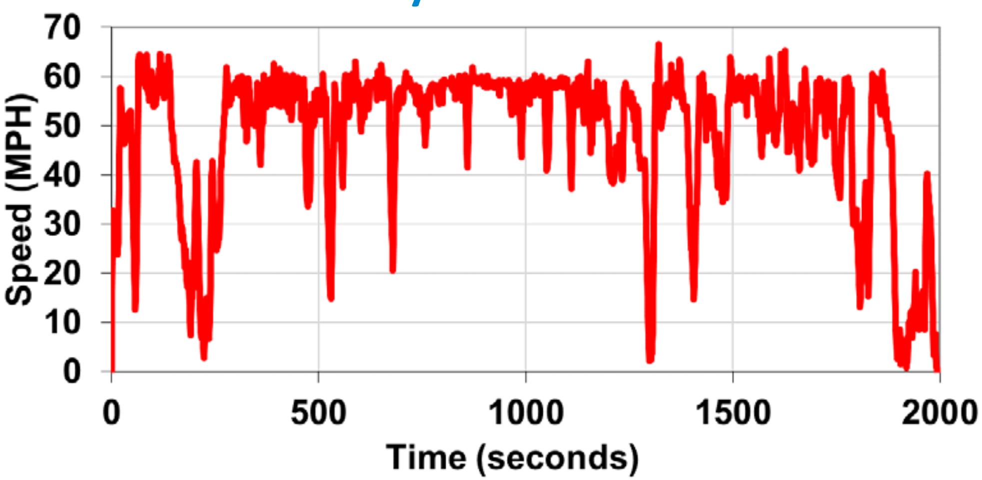
**FASTSim Cost Modeling Step Progress**

1. **(Complete)** Selected initial set of vehicles and vocations based on literature[1] and VIUS data

2. **(Complete)** Drive-cycle data for each vehicle class/vocation extracted from Fleet DNA

3. **(Complete)** The DRIVE tool has been used to create representative drive-cycles

**Class 8 Line Haul Representative Drive-Cycle from DRIVE**




| Vehicle Class | Vocation |
|---|---|
| Class 2b | Small Van |
| Class 3 | Enclosed Van |
| Class 3 | School Bus |
| Class 3 | Service, Utility Truck |
| Class 4 | Walk-In / Multi-Stop, Step Van |
| Class 5 | Utility, Tow Truck |
| Class 6 | Construction, Dump Truck |
| Class 7 | School Bus |
| Class 8 | Construction, Dump Truck |
| Class 8 | Line Haul |
| Class 8 | Refuse, Garbage Pickup |
| Class 8 | Tractor Trailer |

**Vehicles and vocations determined and drive-cycle data obtained**

1. Marcinkoski, J. V. (2016, June 19-22). Driving an Industry: Medium and Heavy Duty Fuel Cell Electric Truck Component Sizing. Montreal.

# *Accomplishments and Progress (2/6):* Powertrain cost optimization using FASTSim

**FASTSim Cost Modeling Step Progress**

4. **(In Progress)** FASTSim is being updated to optimize M/HDV with cost targets (GRPA, FCTO) and vehicle attribute data[2]

5. **(In Progress)** Vehicle and vocation cost optimization and validation is on-going

| Vehicle (Class) | Drag Coefficient | Frontal Area ($m^2$) | Glider Mass (kg) | Center of Gravity Height (m) |
|---|---|---|---|---|
| Enclosed Van (3) | 0.71 | 6 | 3700 | 0.31 |
| Parcel Delivery (4) | 0.70 | 6 | 3700 | 0.31 |
| Regional Truck (8) | 0.80 | 9.5 | 13600 | 0.53 |
| Line Haul (8) | 0.6 | 8.5 | 13600 | 0.53 |
| Transfer Truck (8) | 1 | 5.6 | 13600 | 0.53 |
| Drayage Truck (8) | 0.8 | 6 | 13600 | 0.53 |

- Preliminary results for conventional, HEV, BEV, and FCEV powertrains (PHEV ongoing)
- FCTO Ultimate targets are used for 2040

**FASTSim is being updated and validated to optimize M/HDV vehicles**

| | Target | 2020 | Ultimate |
|---|---|---|---|
| Battery | Battery Mass [kg/kWh] | 4.2 | 2.5 |
| | Battery Price HEV ($/kW) | 20.0 | 13.0 |
| | HEV Battery Cost [$/kWh] | 194.4 | 80.0 |
| | PHEV Battery Cost [$/kWh] | 194.4 | 80.0 |
| | PEV Battery Cost [$/kWh] | 194.4 | 80.0 |
| Fuel Cell | Hydrogen storage (kWh/kg) | 1.5 | 2.2 |
| | Fuel cell specific power (kW/kg) | 0.65 | 0.65 |
| | Fuel cell cost ($/kW) | 40 | 30 |
| | Hydrogen tank cost ($/kWh) | 10 | 8 |
| | Hydrogen fuel price ($/kg) | 4 | 4 |

2. Wang, L. et al. "Quantitative Effects of Vehicle Parameters on Fuel Consumption for Heavy-Duty Vehicle," SAE Technical Paper 2015-01-2773, 2015.

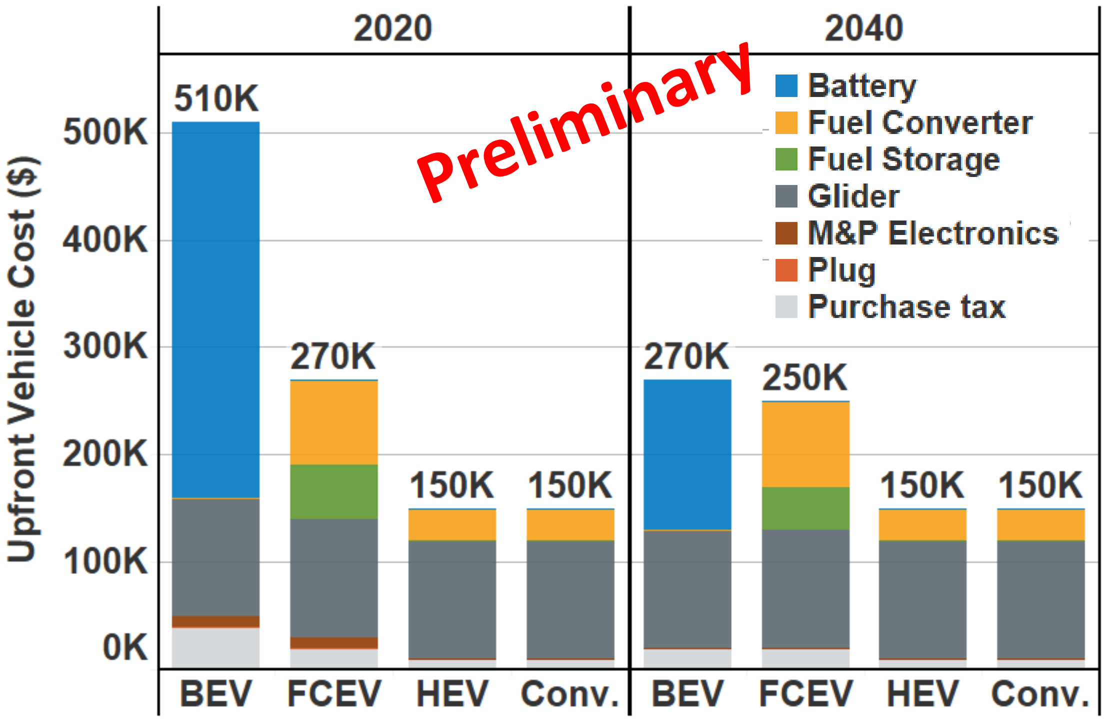
## *Accomplishments and Progress (3/6):* FASTSim Results: Class 8 Line Haul Case Study


### FASTSim Class 8 Line Haul Key Results

Preliminary

| Class 8 Line Haul | 2020 Technology | | | | 2040 Technology | | | |
|---|---|---|---|---|---|---|---|---|
| | BEV | FCEV | HEV | CONV | BEV | FCEV | HEV | CONV |
| Est. MSRP ($k) | 470 | 260 | 150 | 140 | 250 | 240 | 150 | 140 |
| Fuel economy (mi/gge) | 15 | 10 | 7 | 7 | 16 | 10 | 7 | 7 |
| Mass (thousand kg) | 33 | 30 | 29 | 28 | 30 | 29 | 29 | 28 |

### FASTSim Class 8 Line Haul Upfront Cost



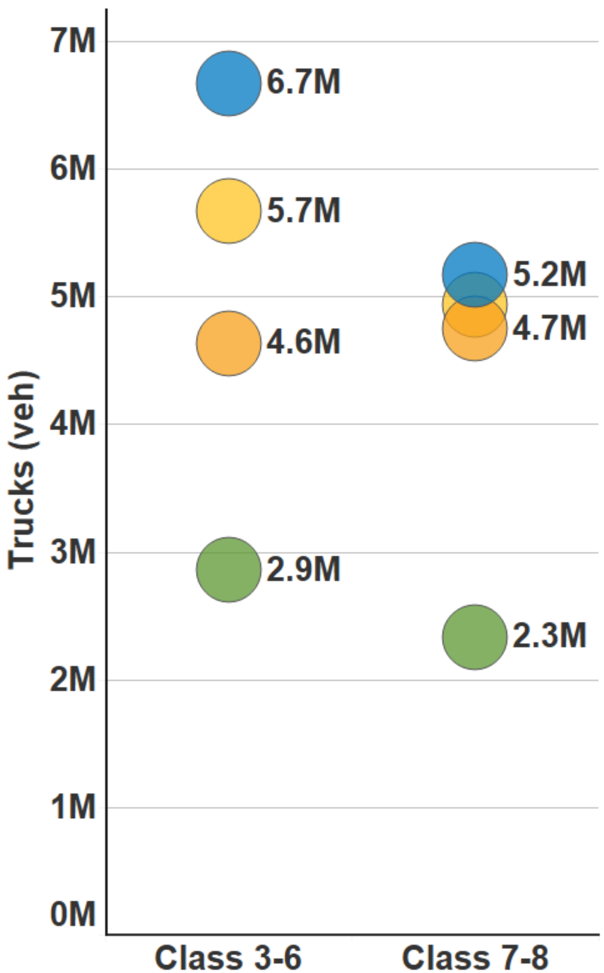

- Preliminary FASTSim results indicate upfront Class 8 Line Haul (500 mile range) FCEV costs more than conventional but less than BEV
- FCEVs have higher fuel economy but are heavier than conventional vehicles (to be validated)
- Fuel, O&M, Opportunity costs, and other potential value streams are not accounted for in FASTSim but will be included in the TCO analysis

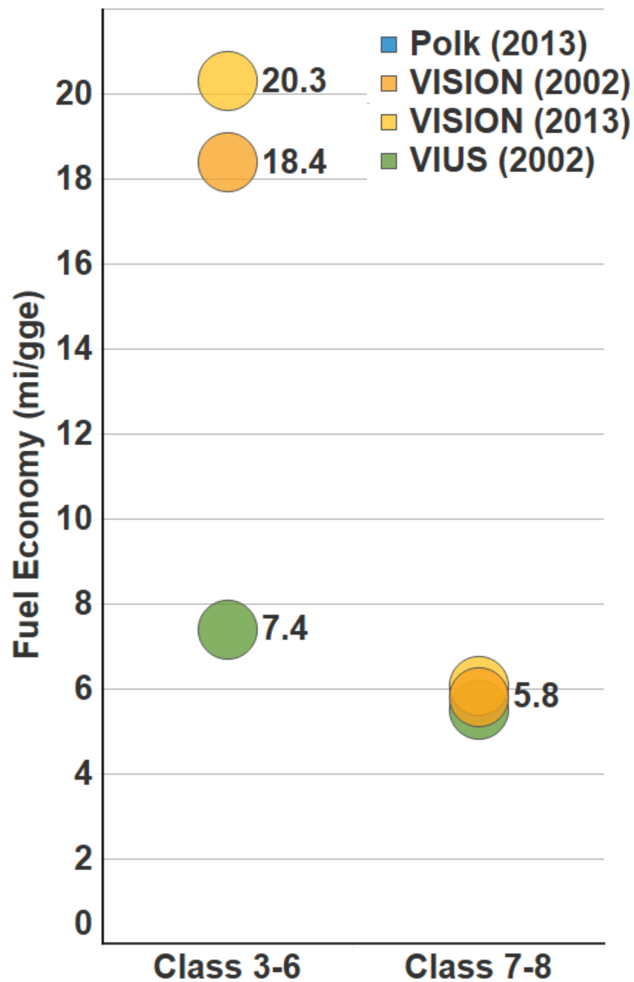
**FASTSim results provide upfront vehicle costs, fuel economy, and mass for TCO analysis**

# *Accomplishments and Progress (4/6):* SERA M/HDV Stock Model: Data Comparison

**SERA Stock Modeling Steps**

1. **(Complete)** Determine and compare data availability across various data sources
2. **(In progress)** Incorporate vehicle data into SERA model, match VISION model



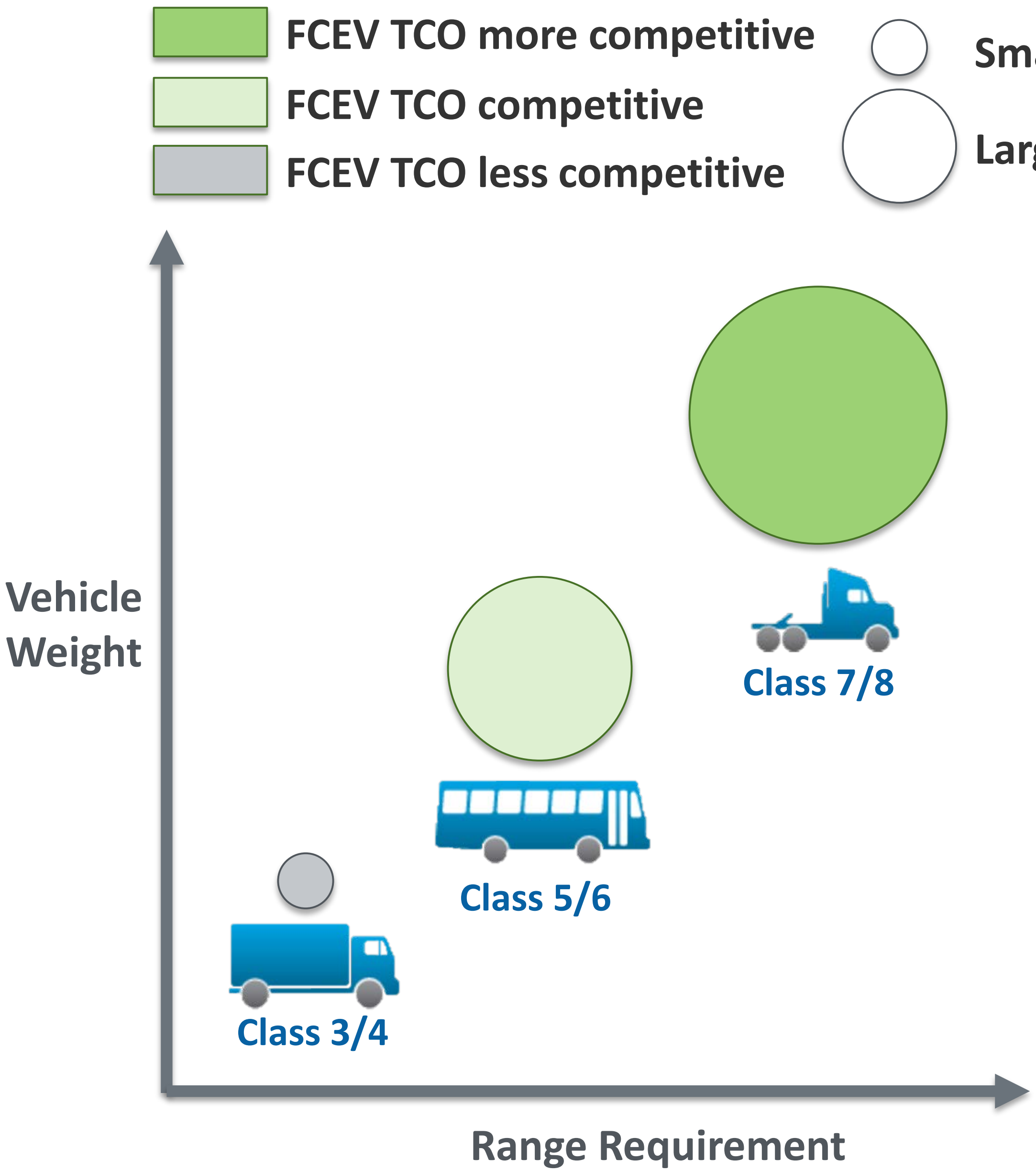




- Polk data shows larger MDV/HDV stock populations
- Fuel economy data from VIUS matches VISION Class 7-8
- VISION and VIUS VMT are consistent for both classes

**Polk data used to disaggregate VISION population, VISION fuel economy and VMT will be used**

# *Accomplishments and Progress (5/6)*

## *Hypothesized* SERA TCO Visualization




### *Hypothesized* SERA TCO Visualization

- SERA TCO results will estimate competitive nature of FCEVs for each class/vocation
- Competitive FCEV TCO will result in higher technology adoptions and future market shares
- Hydrogen demand can be determined based on FCEV M/HDV adoption over time and region in the US

## *Accomplishments and Progress (6/6)*
# Responses to Reviewers' Comments

- N/A as this is a new, FY18 project for FCTO

# Collaboration and Coordination

- **Vanderbilt University – *Modeling***
  - Dr. Yuche Chen supporting vehicle stock model development

- **Cummings, Toyota, FedEx, Nikola – *Peer Reviewers***

# Remaining Challenges and Barriers

## FASTSim Model

- Continue to validate model outputs for vehicle cost, fuel economy, and weight
- Evaluate climate effects on auxiliary power load

## SERA Stock Model

- Need to evaluate tradeoffs between having increased stock model detail (region, vocation, and vehicle specific VMTs, survival rates, and fuel economies) and exactly matching the VISION model
- Spatial distribution of VMT across regions could be challenging give time and resource limits. Could be a potential future enhancement

## SERA Total Cost of Ownership Analysis

- Limited data on fuel cell and battery truck upfront costs, weight, O&M costs, opportunity costs, and other potential value streams

# Future Work and Potential Work

**FY18 Project Plan**

## FASTSim Cost Modeling

- Define vehicles/vocations ☑
- Obtain relevant data ☑
- Complete modeling ☐

## SERA Stock Modeling

- Evaluate data sets ☑
- Develop stock model ☐

## SERA TCO Modeling

- Integrate FASTSim outputs input into SERA ☐
- Acquire indirect cost data ☐
- Complete TCO modeling ☐
- Sensitivity analysis ☐

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

### FASTSim Cost Modeling (FY18)

- Continue updating and validating FASTSim M/HDV outputs (cost, fuel economy, weight)
- Complete modeling for all vehicles/vocations

### SERA Stock Modeling (FY18)

- Integrate VISION and Polk/IHS data into SERA model
- Verify alignment between VISION and SERA

### SERA TCO Modeling (FY18)

- Review and compile available data on O&M, opportunity costs, and other value streams
- Complete spatial and temporal TCO modeling
- Complete sensitivity analysis on cost assumptions

### Potential Future Scope (FY19+)

- Integrate with **H2@Scale** through temporal and spatial supply, demand, and storage requirements
- Integrate TCO data into ADOPT vehicle choice model
- Evaluate cost-volume feedback loop between production volume ramp up and cost curves
- Evaluate other vehicle segments (rail, marine)

# Technology Transfer Activities

- ***FASTSim*** is currently available (LDV) and the updated version (with M/HDV capabilities) will be made available after project completion
  - https://www.nrel.gov/transportation/fastsim.html

- Licensing of ***SERA*** model is being considered

- Analysis visualizations may be added to NREL's Hydrogen Demand and Resource Analysis ***(HyDRA)*** tool
  - https://maps.nrel.gov/hydra/

# Summary

### Relevance

- Expansion of systems analysis models that assess cost and market barriers to fuel cell vehicle adoption
- Provide stakeholders a broad assessment of medium/heavy duty fuel cell vehicle market opportunities and guide future DOE investment

### Approach

- FASTSim for vehicle optimization to obtain vehicle cost, fuel economy, and weight
- SERA for stock modeling using VISION, Polk/IHS data
- SERA TCO modeling direct costs, opportunity costs, and other value streams

### Accomplishments and Progress

- Vehicle segmentation and drive-cycle data obtained for FASTSim analysis
- Initial Class 8 Line Haul FASTSim results acquired, undergoing verification/validation
- VISION, Polk/IHS, and VIUS data evaluated and being integrated into SERA

### Collaboration

- Vanderbilt University (modeling); Cummings, Toyota, FedEx, Nikola (peer reviewers)

### Current and Potential Future Work

- Complete validation of updated M/HDV FASTSim model and results
- Complete SERA stock model and alignment with VISION
- Complete TCO modeling by integrating FASTSim results and cost data into SERA
- **Potential:** Integrate results into **H2@Scale** analysis temporal/spatial analysis

# Thank You

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