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 End: September, 2018 35% complete	**A. Future Market Behavior** • Assessing competitiveness of fuel cell M/HDVs **C. Inconsistent Data, Assumptions & Guidelines** • Consistent modeling methodology using established cost/price targets **D. Insufficient Suite of Models and Tools** • Update powertrain optimization models for M/HDVs and expand the national stock model
Budget	**Partners**
Total Project Funding: $150k • FY18: $150k Total DOE funds received to date: $150k	**University of Vanderbilt** • Dr. Yuche Chen

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

Acronyms

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

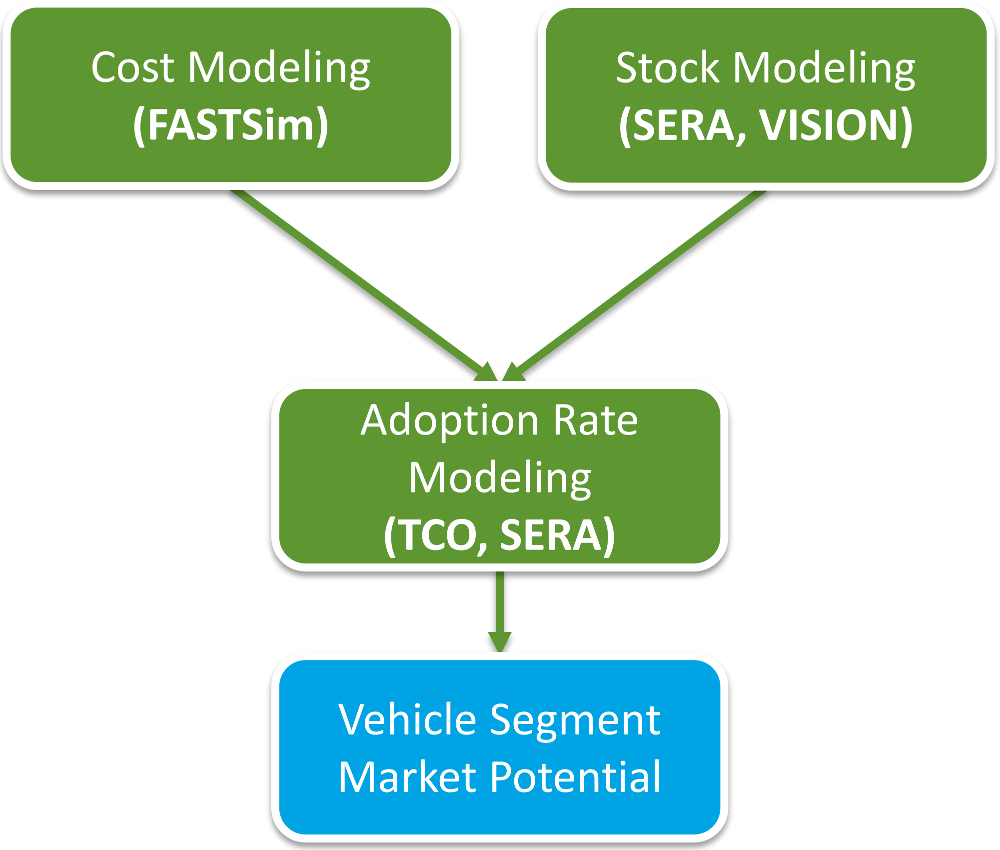
Orange = Data
Green = Model
Blue = Results

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

1. Vehicle/Vocation Assessment

↓ *Vehicles and vocations*

2. Fleet DNA Drive-Cycle Data

↓ *Multiple drive-cycles by vocation*

3. DRIVE

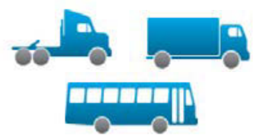
↓ *Representative drive-cycle for vocation*

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

↓

Vehicle Cost
Fuel economy
Weight

Orange = Data
Green = Model
Blue = Results



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

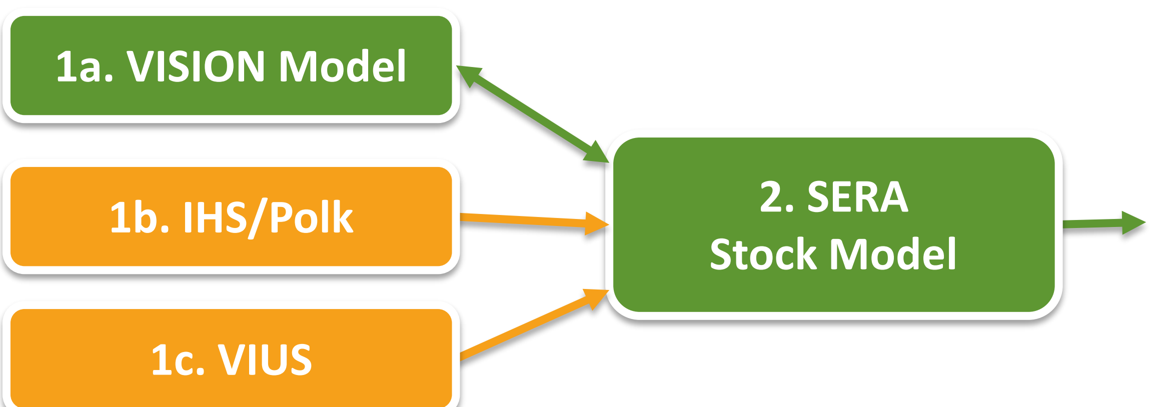
Vehicle/vocations assessed in FASTSim to determine cost, fuel economy, and weight

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

SERA Stock Modeling Steps

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



Stock, VMT, energy usage by region, vehicle, vocation, and time

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

1a. Cost Modeling **(FASTSim)**

1b. Stock Modeling **(SERA, VISION)**

Vehicle cost
Fuel economy
Weight

Stock
VMT
Energy Usage

2. Adoption Rate Modeling **(TCO, SERA)**

Lowest cost vehicle technology by region

3. Vehicle Segment Market Potential

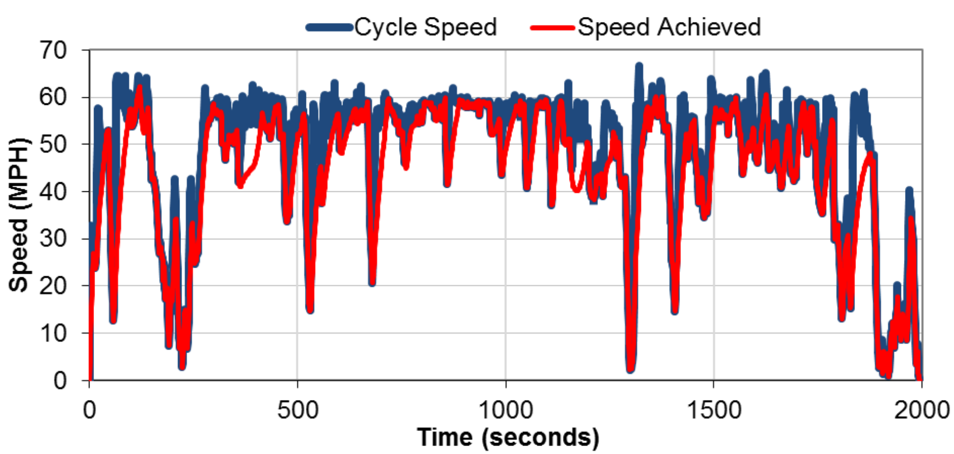
Market potential for FCEVs

Accomplishments and Progress (1/4): 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

Ex. 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 (2/4): 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

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

Vehicle	Drag Coefficient	Frontal Area (m^2)	Glider Mass (kg)	Center of Gravity Height (m)
Class 3 Enclosed Van	0.714	6	3694	0.305
Class 4 Parcel Delivery	0.698	6	3694	0.305
Class 8 Regional Truck	0.796	9.5	13625	0.53
Class 8 Line Haul	0.6	8.5	13625	0.53
Transfer Truck	1	5.61	13625	0.53
Drayage Truck	0.8	6	13625	0.53

- Preliminary results for conventional, HEV, BEV, and FCEV powertrains (PHEV ongoing)
- Different auxiliary power requirements may be used to evaluate climate considerations

	Target	2020	2040
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

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

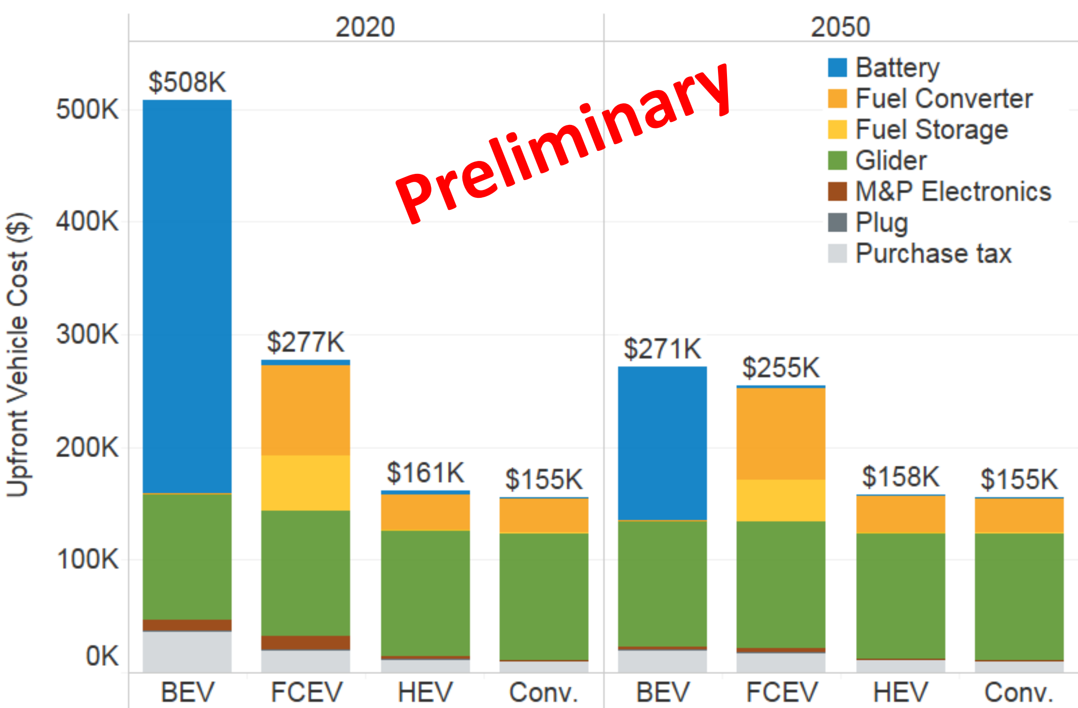
Accomplishments and Progress (3/4): FASTSim Results: Class 8 Line Haul Case Study

FASTSim Class 8 Line Haul Key Results

Preliminary

Class 8 Line Haul	2020 Technology				2050 Technology			
	BEV	FCEV	HEV	CONV	BEV	FCEV	HEV	CONV
MSRP ($k)	471	257	149	144	251	236	146	144
Fuel economy (mi/gge)	15.1	9.8	6.8	6.5	15.9	10	6.8	6.5
Mass (thousand kg)	32.9	30.1	28.6	28.4	30.2	29.3	28.5	28.4

FASTSim Class 8 Line Haul Upfront Cost (no O&M / Opportunity Costs)



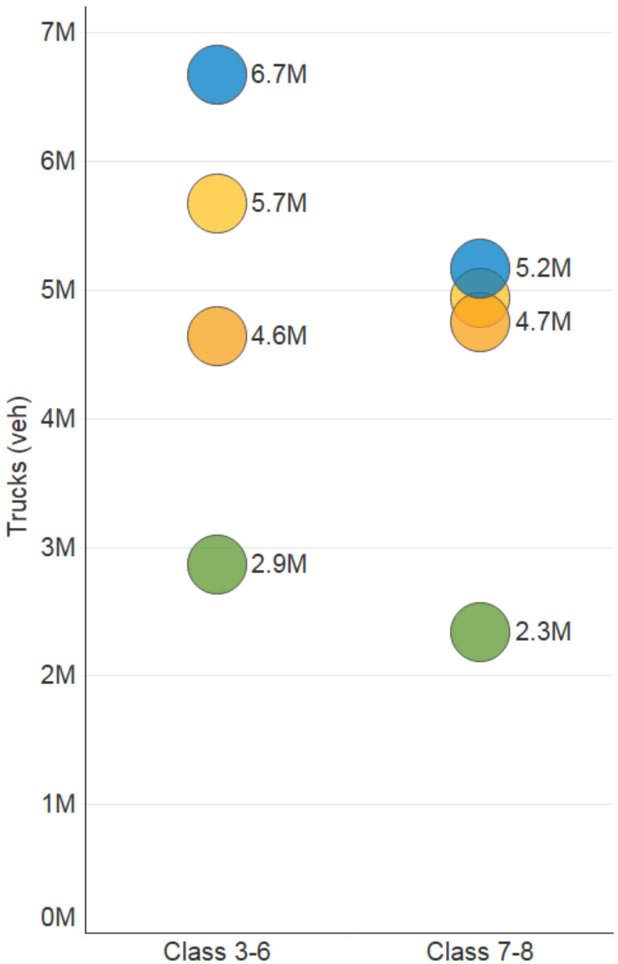
- Preliminary FASTSim results indicate upfront Class 8 Line Haul costs higher than conventional but lower than BEV
- FCEVs have higher fuel economy but are heavier than conventional vehicles (to be validated)
- Fuel, O&M, Opportunity costs, and other potential value streams are not accounted for in FASTSim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

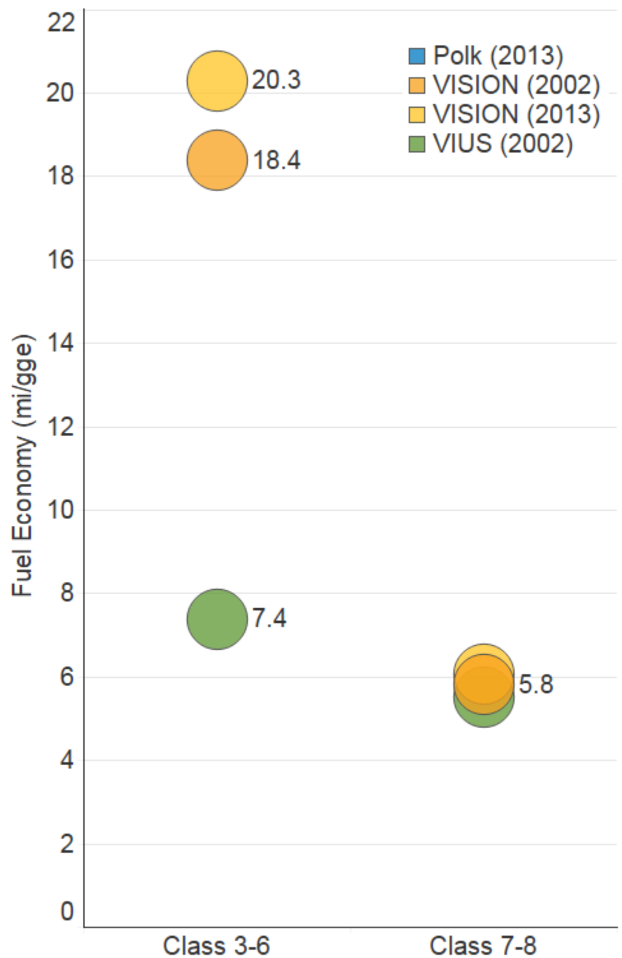
FASTSim results provide upfront vehicle costs, fuel economy, and mass for TCO analysis

Accomplishments and Progress (4/4): 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 VISION matches VIUS C7-8
- 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
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

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

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 ☐

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

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

SERA TCO Modeling
- 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
- Evaluate other vehicle segments (rail, ships, planes)
- Integrate with **H2@Scale** through temporal and spatial supply, demand, and storage requirements
- Evaluate cost-volume feedback loop between production volume ramp up and cost curves

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 results from FASTSim acquired, undergoing verification/validation
- VISION, Polk/IHS, and VIUS data evaluated and being integrated into SERA

Collaboration

- Vanderbilt University

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:** Evaluate other vehicle segments and integrate results into **H2@Scale** analysis

Thank You

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Reviewer-Only Slides

Critical Assumptions and Issues

1. Data Availability
    a. Limited data to verify electric truck upfront costs and weight
    b. Limited data to verify indirect (O&M) and opportunity costs
    c. Regional cost differences depend on data availability
    d. Assume infrastructure costs are rolled into fuel costs

2. Stock Model Fidelity
    a. Detailed travel data is needed for each vehicle/vocation if VMT is to be split between specific regions of interest
    b. Temporal travel detail (hourly) is needed for proper assessment of demand charges – outside of current scope

Publications and Presentations

N/A at this time

Data Management Plan

- This project will maintain compliance with data management requirements of the Department of Energy and abide by the Office of Energy Efficiency and Renewable Energy data sharing and preservation requirements.
- To the greatest extent and with the fewest constraints possible, this project will make digital research data available to, and useful for, the broader scientific community, industry, and the public.
- Technical reports, journal article accepted manuscripts, software, and scientific research datasets will be submitted to OSTI through the DOE Energy Link System. Data from this project deemed appropriate for public access will be made available through the NREL Data Catalog
- Data in this public release will be in a machine-readable digital format (e.g., comma-delimited).
- This project will not generate or use Personally Identifiable Information (PII). Any data containing national security implications, business confidentiality, or intellectual property will not be released in accordance with all laws and DOE regulations, orders, and policies.