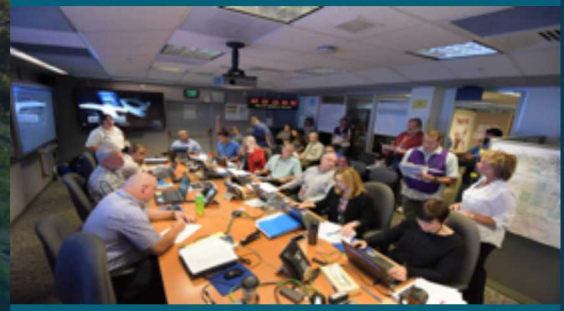
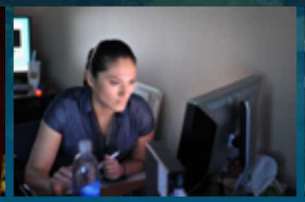
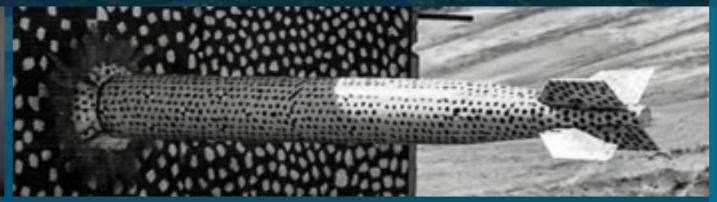
SAND2020-4427C

Sandia National Laboratories

ParaChoice Model







Project ID# van019

Date: 6/2/2020

2020 DOE
Vehicle Technologies
Office
Annual Merit Review

PRESENTED BY

Steven Wiryadinata

Team members: *Camron Proctor (P.I.)*

This presentation does not contain any proprietary, confidential, or otherwise restricted information

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

Overview

Timeline

- Start date: FY14
- End date: FY20
- Percent Complete: FY20 48%*

Budget

- Total FY 2020 Project Funding:
  - DOE Share: $287K
  - Contractor Share: N/A
- Funding for FY 2018: $200k
- Funding for FY 2019: $200k

Barriers and Technical Targets

- Accelerate the development and adoption of sustainable transportation technologies by identifying opportunities for impactful incentives and investments.
- Highlight sensitivities and tradeoffs in the highly uncertain transportation sector.

Partners: Interactions/ Collaborations

- Argonne National Lab (ANL)
- National Renewable Energy Laboratory (NREL)
- Energetics
- Lawrence Berkeley National Lab (LBNL)

*As of 4/15/2020

Relevance & Objective

Lifetime Project Goal: Systems level analysis of the dynamics within the light-duty vehicle (LDV) and heavy-duty vehicle (HDV) fleets, fuels, infrastructure mix, and emissions

- Use parametric analysis to:
  - Identify trade spaces, tipping points & sensitivities
  - Understand & mitigate uncertainty introduced by data sources and assumptions

Project objective: Assess evolving LDV and HDV technologies, fuels, and infrastructure. Identifying opportunities to reduce their contributions to emissions and petroleum consumption.

This year:

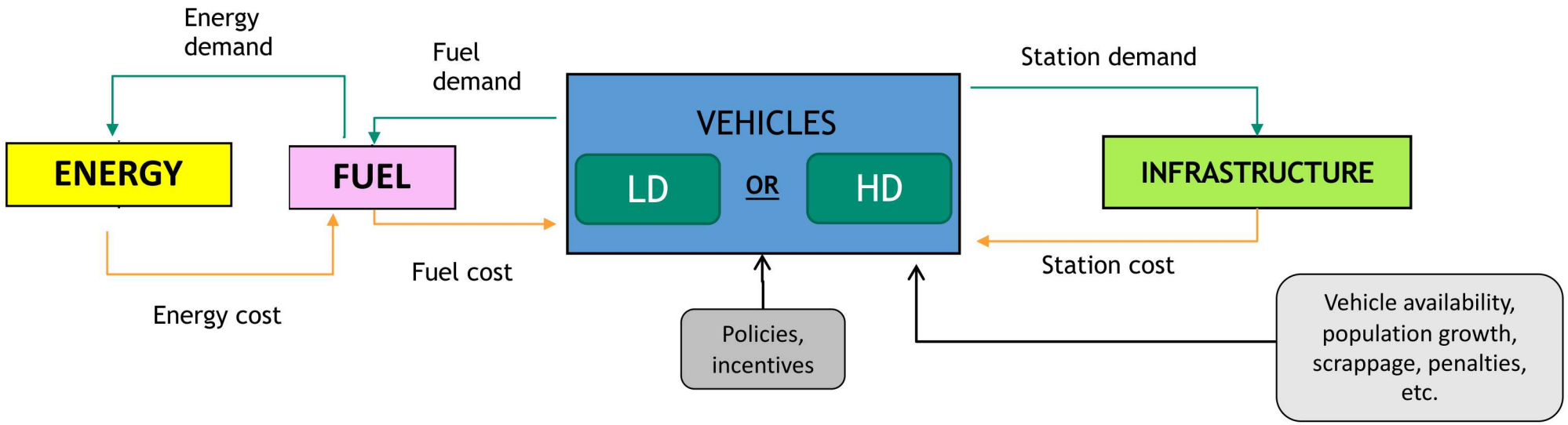
- Complete updates to HDV capability begun in FY19
  - Update HDV model capability to handle more bodies and vocations
  - Work with partners at Argonne to increase the number of modeled vehicle and powertrain combinations
- Integrate LDV and HDV modeling capabilities
  - Model the combined effects of LDV and HDV demands on the energy, fuel and infrastructure segments to account for their cumulative effects
  - Identify opportunities to model technology spillovers and positive externalities between segments
- Participate in Total Cost of Ownership (TCO) analysis
  - Lead: Data collection and analysis task with ANL, and Online data and tools tasks
  - Contribute to other sub-teams

ParaChoice provides decision & investment guidance despite significant uncertainty

Milestones

Quarter	Milestone & Go/No-Go	Status
FY20 Q1	**Milestone:** Presentation to HQ on proposed test case, conditions and assumptions for integrated LDV-HDV model demonstration. Identify methodologies for tangential technology development interactions.	Complete
FY20 Q2	**Milestone:** Presentation to HQ on additional HDV vehicle types using HDV-only model	Complete
FY20 Q3	**Milestone:** Presentation to HQ on integrated LDV-HDV analysis results	On Track
FY20 Q4	**Milestone:** Publish model results; send citation to VTO	On Track
FY20 Q4	**Go/No-Go**: Insufficient data to develop model	On Track

Approach: Capture the dynamics of infrastructure, fuel and policy on vehicle adoption



Begins with today's energy, fuel, and vehicle stock and projects out to 2050

- At each time step, vehicles compete for share in the stock based on value to consumers and external factors such as policies

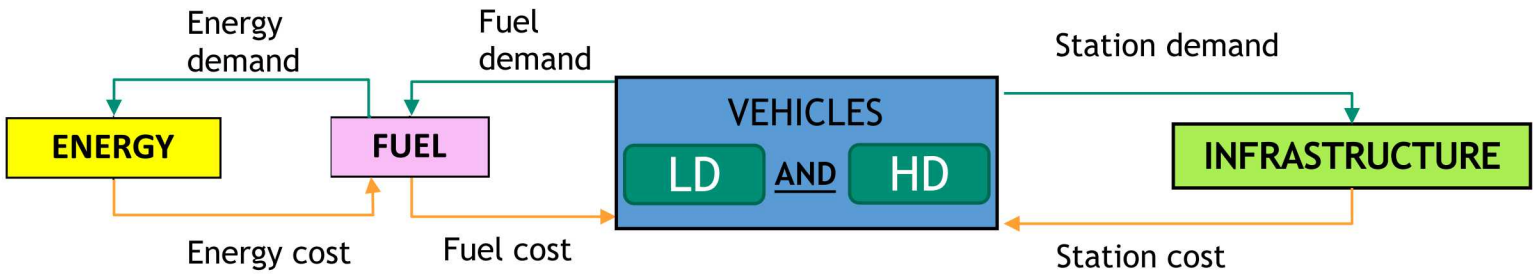
Variables change with time and demand

Variety of output options, including:

- Sales Fractions
- Vehicle Stock
- Emissions
- Fuel Consumption
- Trades & Sensitivities

ParaChoice models the complex interactions of supply and demand for energy, fuel, and vehicle stock

Approach: Integrate the LD and HD vehicle evolution projections by capturing the dynamics of simultaneous fuel, energy and infrastructure use.



LDVs and HDVs can take advantage of the same fuel production

Compare results of independent analysis against integrated analysis using the same inputs

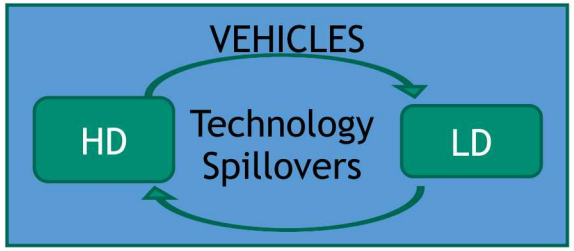
Enabling Assumptions:

- Bound the analysis space to on-road LDV and HDV.
  - e.g. Will not model medium duty vehicles, off-road vehicles, rail, maritime, aerospace
- LDV/HDV conventional technology is sufficiently matured that spillover effects only apply to Alternative Fuel Vehicles (AFVs)

Integration of the shared infrastructure through modeling will capture the supply-demand effects of growing both segments in parallel.

Approach: Capture the effects of technology spillover between LDV and HDV segments.

Technology spillover is defined as knowledge / resource transfer among sectors that accelerates the development process and consequently vehicle sales of the recipient sectors, e.g. more advanced battery development by way of more light duty EV sales can benefit advancement to heavy duty EV



Implementation in ParaChoice:

- Establish a macro-level relationship between LDV and HDV sales using real-world sales data of top LDV and HDV manufacturer
  - Test the hypothesis: The difference in percentage change in quarter-to-quarter sales of a powertrain in LDV (or HDV) improves sales in HDV (or LDV) with some delay time.
- Adjust the calculated sales fractions of LDV (HDV) using any established relationships, as illustrated below

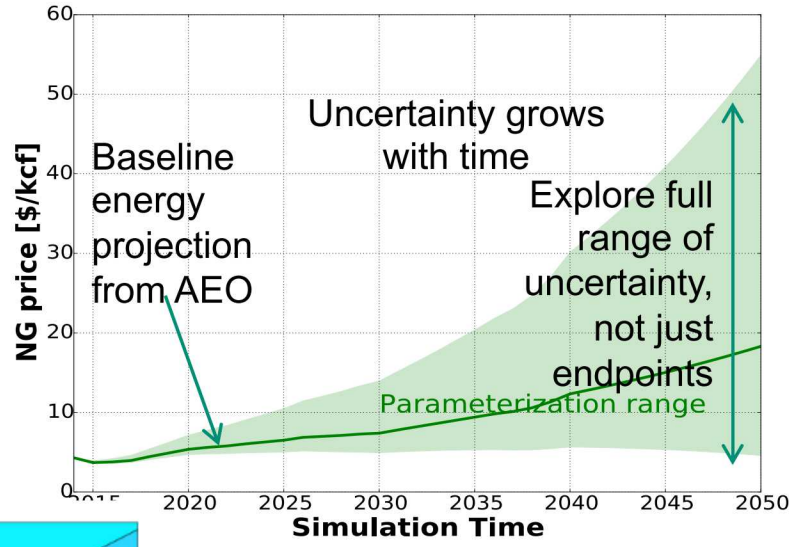
Capturing spillovers between LDV and HDV will illustrate the synergistic effects of technology development in vehicles of different class groups

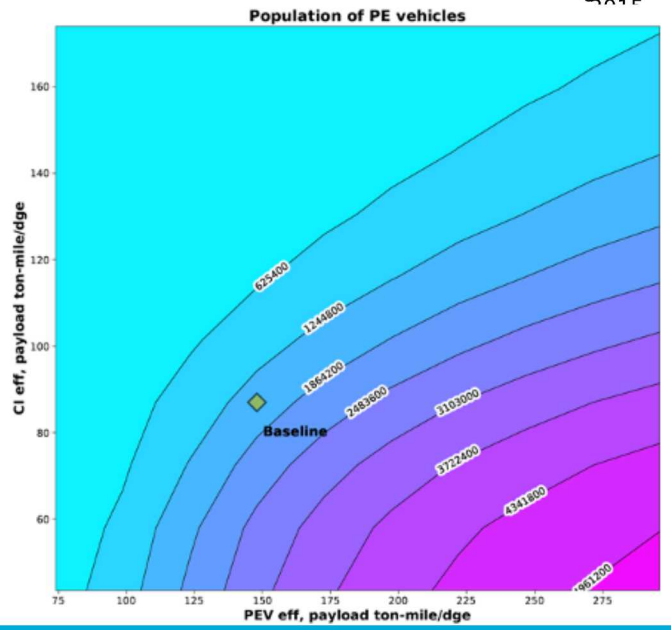
Approach: Use parameterization to understand and mitigate uncertainty introduced by data sources and assumptions

Uniqueness from other DOE models: ParaChoice is designed to explore uncertainty & trade spaces, easily allowing identification of tipping points & sensitivities

- Parametric approach enables:
  - Trade space analyses (vary 2 parameters)
  - Sensitivity analyses (vary many parameters)
- Simulation is run 1000s of times with varying inputs, providing:
  - Perspectives in uncertain energy & technology futures
  - Sensitivities and tradeoffs between technology investments, market incentives, and modeling uncertainty
  - The set of conditions that must be true to reach performance goals

Example parameterization of natural gas prices with multiplier on AEO projection

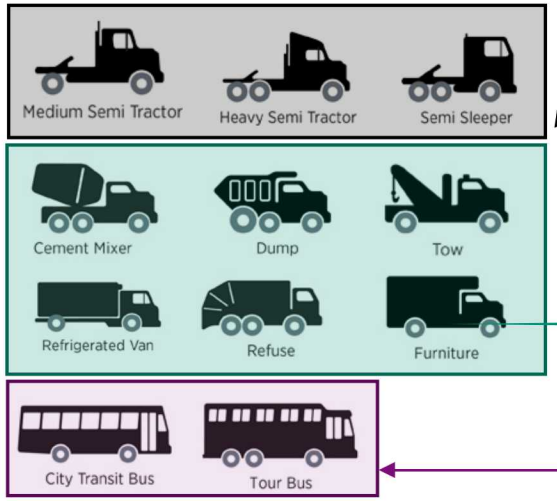




xample
de space
put of two
rameters
varied

Parameterization ranges are designed to explore plausible and ‘what if’ regimes, covering all bases

Approach: Fill in limited HDV data by leveraging multiple sources.



Body	Vocation	CI conventional diesel	CI-ISG diesel mild hybrid	CI-HE diesel hybrid	CNG conventional CNG	LNG conventional LNG	CNG-HE CNG hybrid	LNG-HE LNG hybrid	BE battery electric	CI-PHE diesel plugin hybrid	FC fuel cell
Tractor trailer and straight trucks	Construction	x	x	x					x	x	x
	Food										
	Freight	x	x	x					x	x	x
	Lease/finance										
	Natural resources										
	Manufacturing										
	Services	x	x	x					x	x	x
	Wholesale/retail										
Bus	Bus/transport	x	x	x					x	x	x

Data for vehicles marked x were updated using Autonomie 2019 and vetted against sources on the open literature including NAP Phase 2 study

HDV data from the Freight vocation was substituted for the missing (blue marked) vocations as these are heavily represented by Freight-type applications

Data from the open literature were used to estimate CNG and LNG

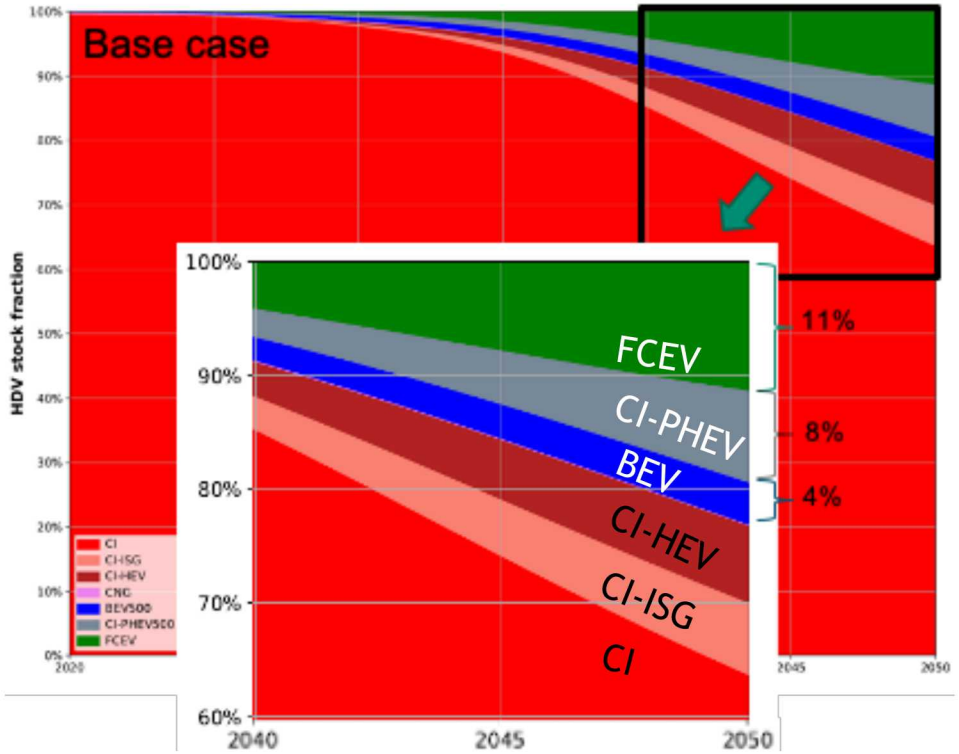
Relative efficiency values between Autonomie's CI and CI-HE were calculated and applied to CNG and LNG to estimate efficiencies of the CNG and LNG hybrid

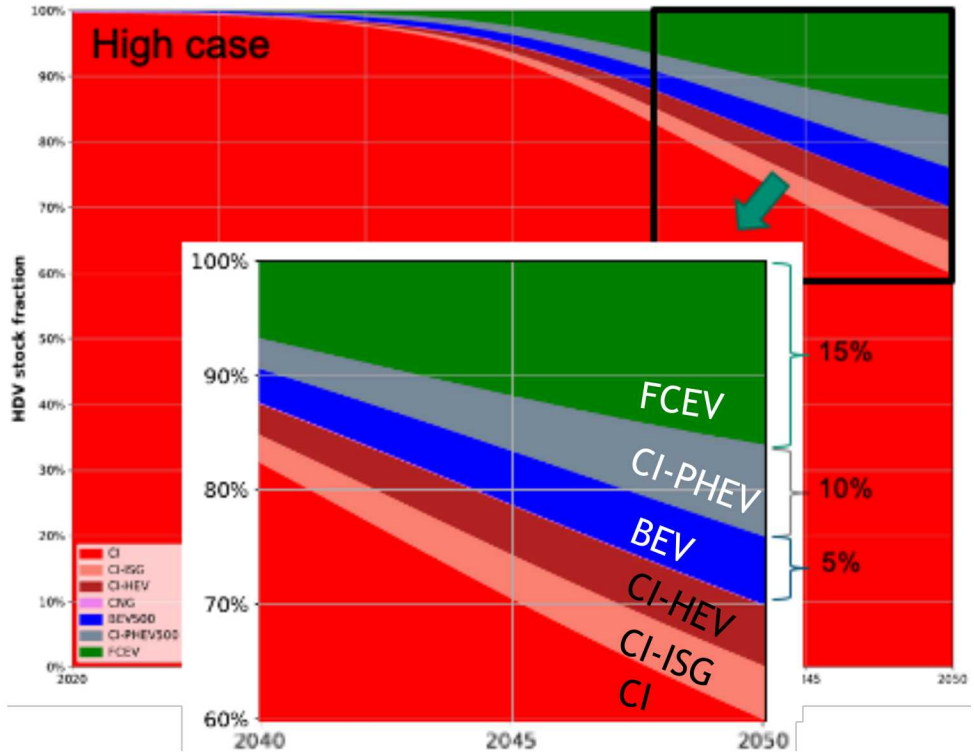
ParaChoice maintains capability to analyze all of the above powertrains, but focuses only on those of interest to VTO

Accomplishments & Progress : We successfully adapted the proven LDV ParaChoice model to the HDV segment

Generally, CI (diesel) vehicles continue to dominate the HDV space. However, battery electric, plug-in hybrid diesel and fuel cell vehicles can see increasing adoption in the long term, with market penetration at 4%, 8%, 11% in 2050, respectively.

Autonomie “High” technology case shows a larger share of FC penetration along with BE and PHE, due to AFVs outpacing CI in vehicle efficiency and closing the gap relative to CI in purchase cost.

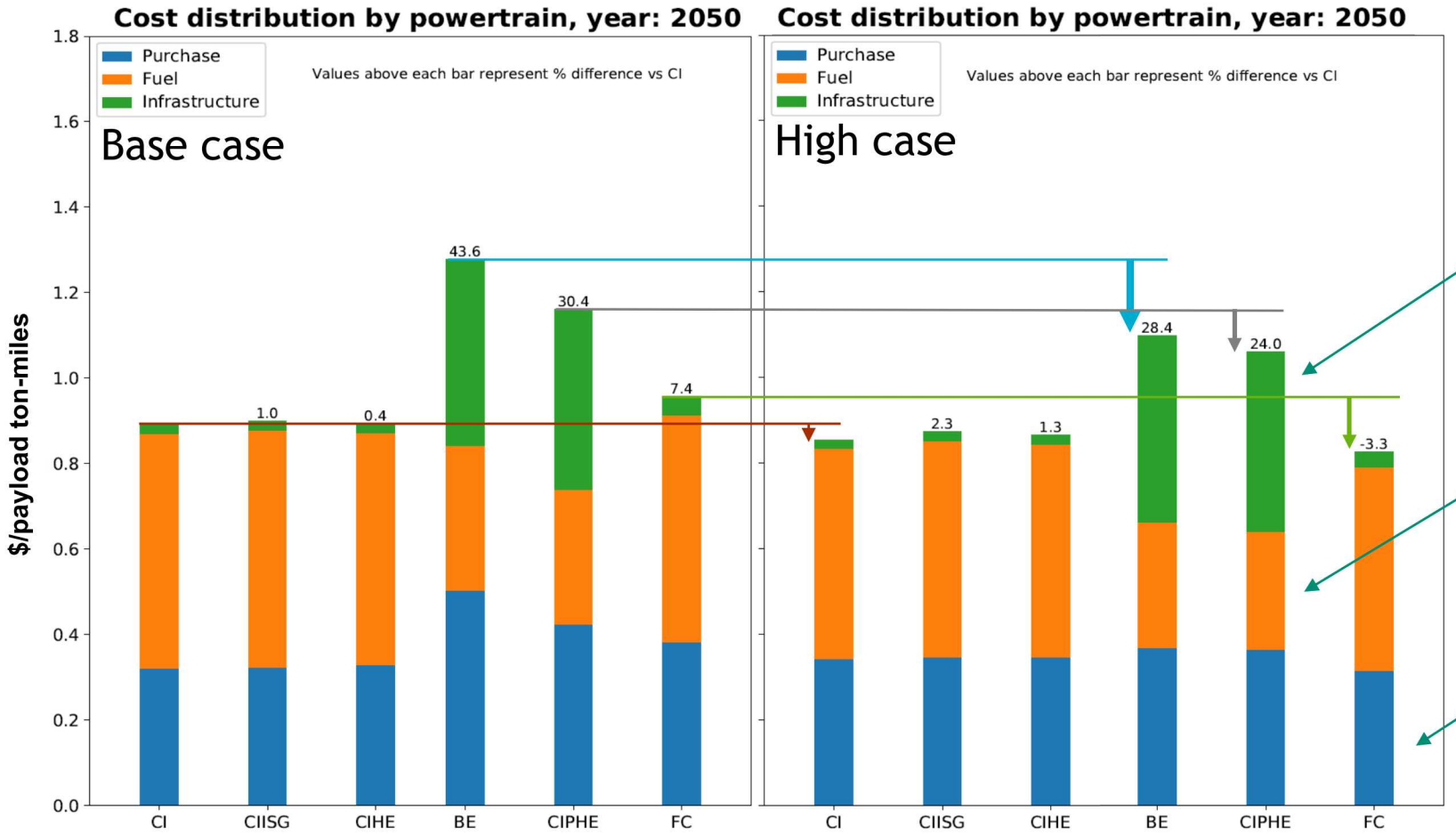




The Fleet-wide HD vehicle stock achieves greater than 20% market share by 2050 even in the base case and meeting VTO targets (High case) makes a significant impact on adoption.

A&P: Meeting VTO targets is projected to have a significant impact on multiple factors influencing adoption of AFVs in the HDV market.

Sales are driven by differences in total costs to operate vehicles of each powertrain. While all non-CI powertrains within each case show cost disparity over diesel across the cost components, AFVs benefit from markedly lower relative costs under the High case scenario.



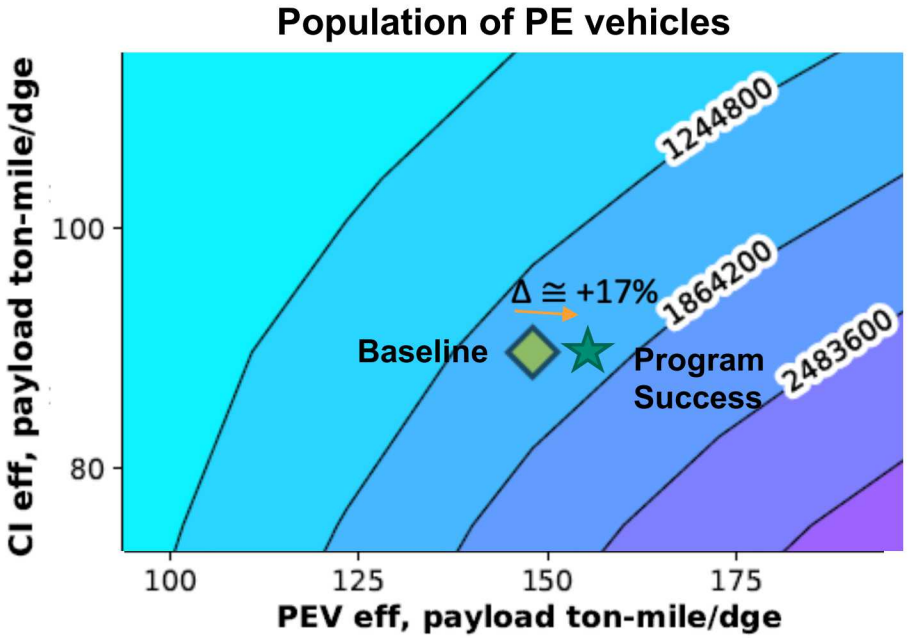
The build out of high power infrastructure for large HDV battery charging, along with the supply infrastructure carries a significant cost despite favorable purchase price and powertrain efficiency.

PEVs benefit from high powertrain efficiencies compared to other powertrain, resulting in lower fuel costs.

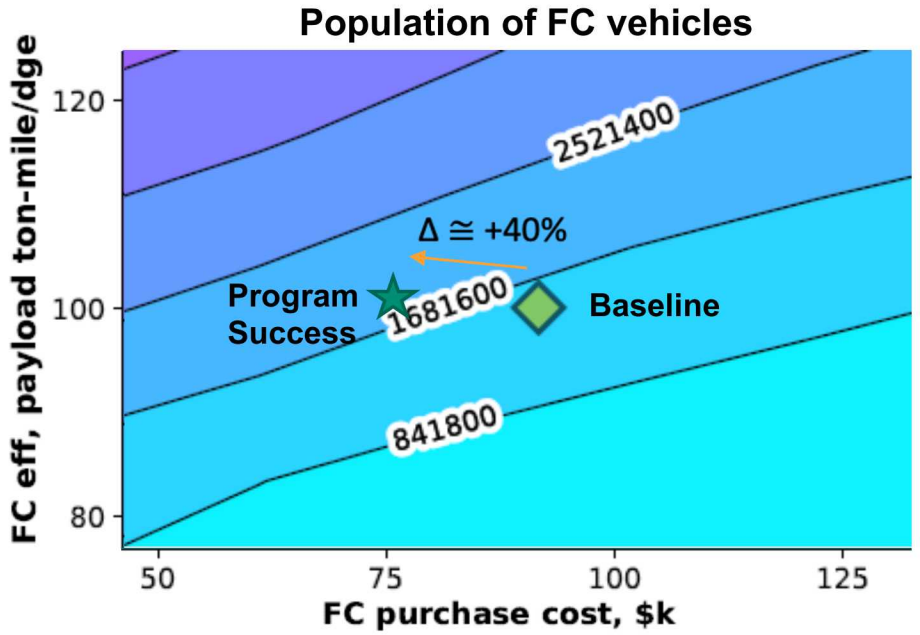
FCEVs show lower total cost in year 2050 relative to CI (at -3.3%), driven largely by purchase cost decrease. Similarly, PEVs show the largest reduction in purchase cost from the Base to High case .

Meeting VTO targets affects major components of costs: fuel and purchase

A&P: We identified key tradeoffs that can be leveraged to increase the adoption of PEVs and FCEVs



Program Success can increase PE population by ~17% of baseline value, corresponding to a decrease 6% decrease in CI population.



Program Success can increase FC population by ~40% of baseline value, corresponding to a decrease 6% decrease in CI population.

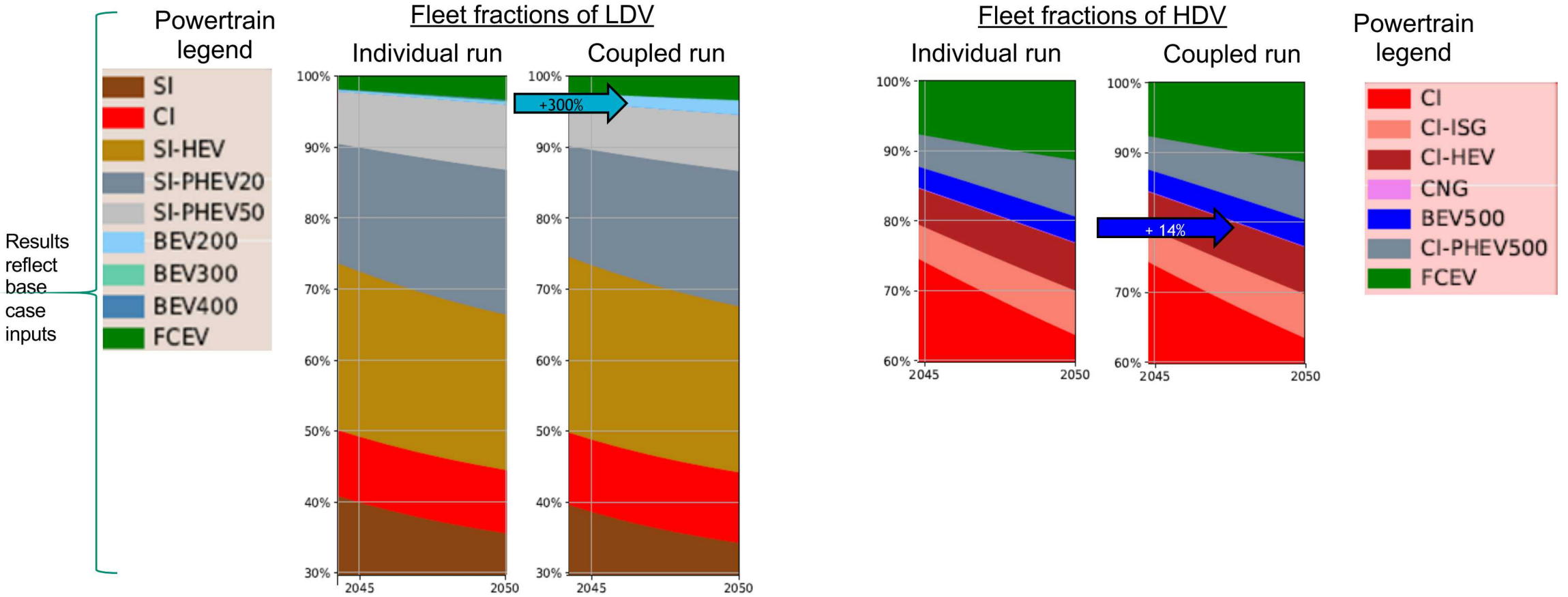
PE adoption is largely dependent on reduction in fuel costs. This suggests that incentivizing fuel-related expenses is crucial.

FC adoption is largely dependent on own technology progress in reducing first cost and fuel expenses, suggesting significance in incentivizing development of fuel and vehicle systems

Accomplishments & Progress

Preliminary results from on-going work in integrating the infrastructure and fuel module of ParaChoice suggest the potential for improved PEV adoption, particularly in the LDV fleet. This can be attributed to avoided costs of charging infrastructure build-out by way of improving utilization of charging stations. As charging infrastructure is a major cost component for PEVs, coupling of infrastructure appears to be beneficial for adoption

Results reflect base case inputs



Shared fuel production and station access enables some marginal cost avoidance

Responses to 2019 AMR Reviewer Comments

Comments from FY19 AMR	Responses
The reviewer advised that a longer-term goal should include some integration of the LDV and HDV segments, as technologies (fuel cells, batteries, etc.) are suitable for both vehicle classes and have potential infrastructure synergies	The primary goal of the FY20 effort is a novel integration of the LDV and HDV vehicle choice models.
The fundamental project challenge observed by this reviewer is that the barriers as described in Slide 2 are too generic.	Clarified the technical barriers on the overview slide to better state the value and impact of ParaChoice.
The reviewer thought the team could elaborate on how it plans to mitigate the risk of unavailable [HDV] data given the newness of some of the vehicle technologies.	Input data were acquired from multiple sources, vetted against and calibrated with each other. For example, Slide 9 shows how multiple sources were used to fill in gaps from our primary input (Autonomie).

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

Partnerships/Collaborations/Interactions

Recent

Argonne National Laboratories – Provides data for BaSce analysis. Provides data for powertrains, efficiency and costs. Peer review of model

Energetics, Lawrence Berkeley National Laboratories – Support as part of VTO analysis portfolio

Fuel Cells Technologies Office – Provides Joint Funding for this effort

Previous

Incorporation of real-world driving cycles in collaboration with: Ford Motor Company, General Electric, American Gas Association

UC Davis – STEPS symposium, renewed interactions with UC Davis including peer review of publications

Model input and review from: ANL, ORNL, NREL, Energetics

Technical critiques on modeling and analysis: DOE, DOT

Workshop Organizing Committee: Toyota, American Gas Association, DOE

HDV performance information: Nikola

Remaining Challenges and Barriers

Uncertainty in AFV Market:

There are significant limitations in data availability for new powertrains/fuels infrastructure, in particular:

- Cost structure of rolling out of charging infrastructure for plug-in electric truck with large battery packs, considering charging power requirements, electrical power production capacity and lengthy charging time
- Many alternative fuel vehicles/powertrains are still in the prototype phase and have no practical real-world data on operating factors such as fuel efficiency and operating life.
- The transportation community is currently investing heavily in new materials, processes, energy pathways and general technology. These technologies could have significant impacts on adoption.

Proposed Future Work- We will continue to develop the capabilities of ParaChoice through the integration of LDV and HDV models

Ongoing

FY20 – [Q3 Milestone] Presentation to HQ on integrated LDV-HDV analysis results

FY20 – [Q4 Milestone] Publish results of LDV-HDV integration modeling

FY20 – Continue work as part of TCO working group

To our knowledge, this effort will be the first attempt to model the LDV and HDV segments together to capture any symbiotic effects.

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

Summary

Final Year of ParaChoice in VTO analysis portfolio

Approach

- Unique Parametric capabilities
- Updated HDV ParaChoice
- Integrating LDV-HDV modeling capabilities

Accomplishments

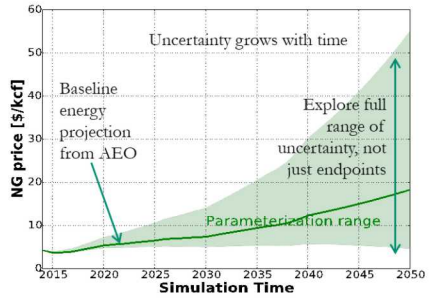
- Significant updates to the HDV capability allow us to:
  - Model the effects of VTO programs on HDV adoption
  - Highlight tipping points and tradeoffs
- Updates to HDV functionality including new powertrains, body types and fuels
- Preliminary effects of integrating LDV-HDV modeling capabilities

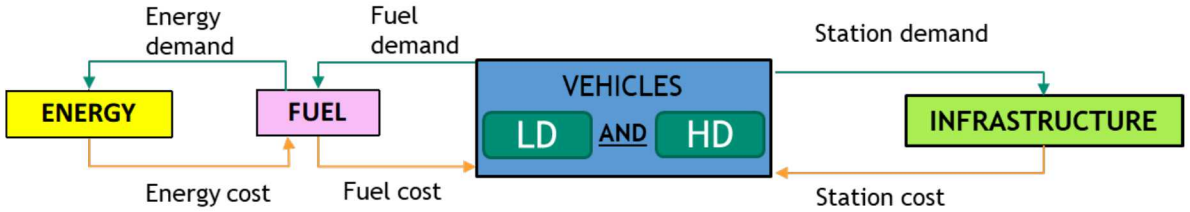
Collaborations

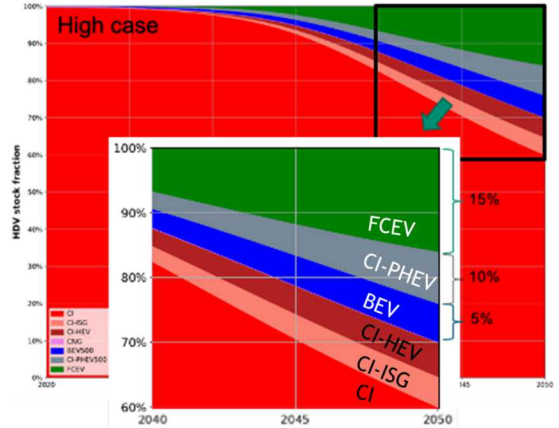
- Expanded collaborations with analysis portfolio laboratories
- Connections with HDV experts
- Results validation against similar models

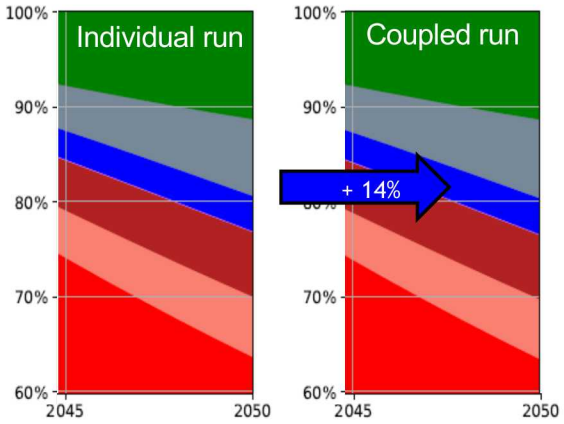
Future Work

- Finish LDV-HDV integration and publish results
- Finish TCO effort



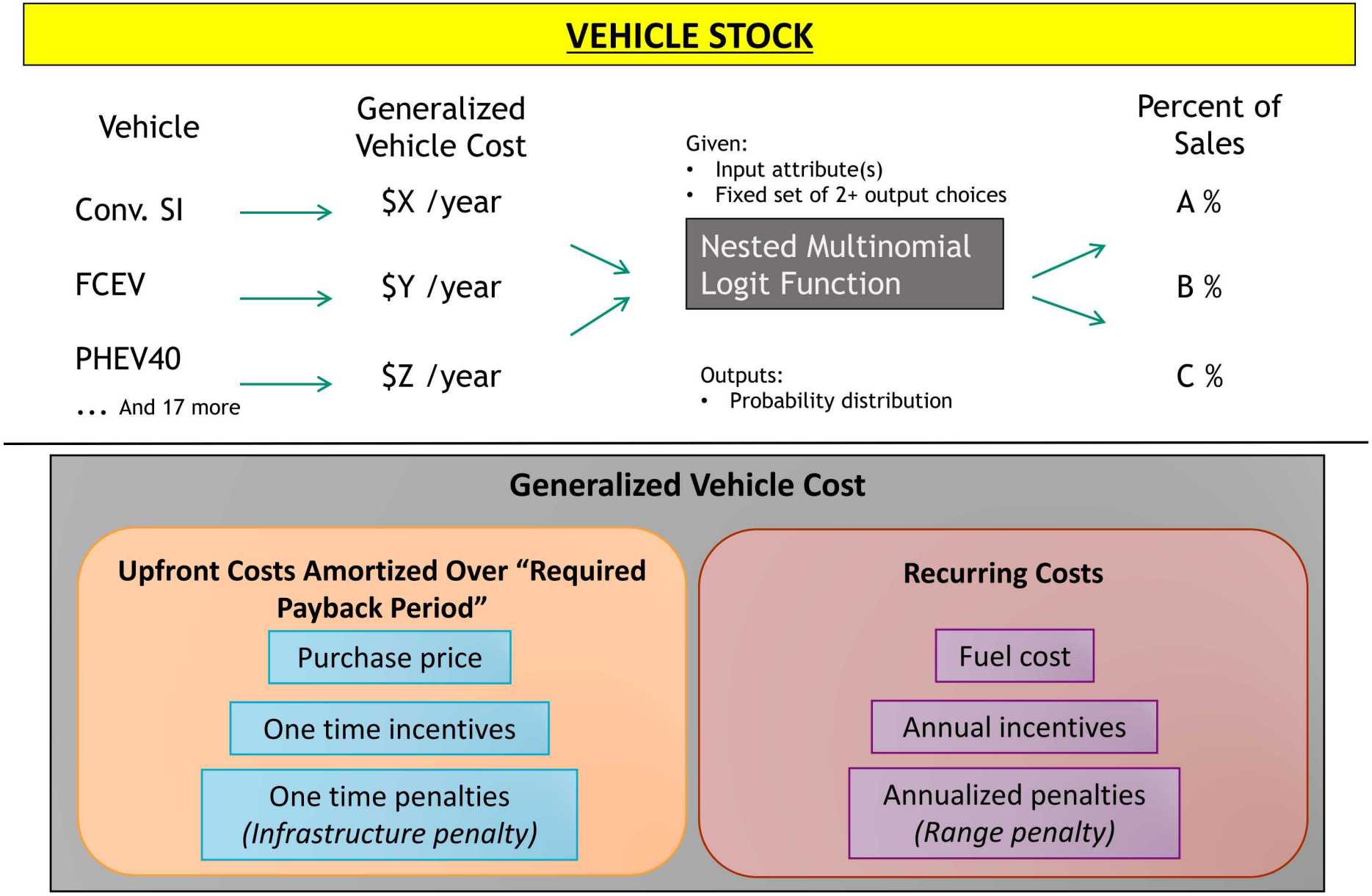




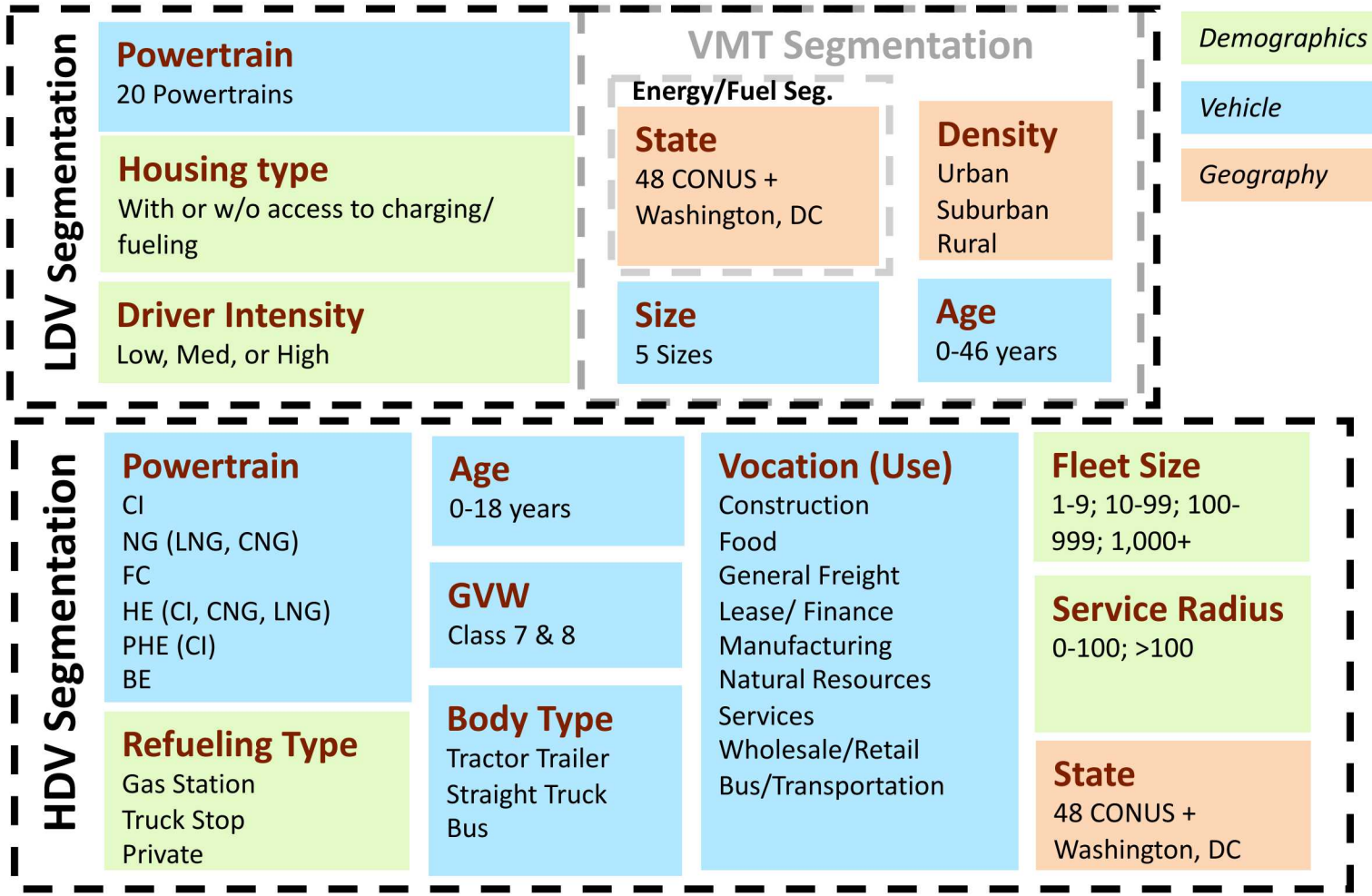


Technical Backup Slides

Approach: At every time step, simulation assesses generalized vehicle costs for each vehicle. Choice function assigns sales based on these costs and updates stock.



Approach: ParaChoice segments vehicles, fuels, & population to understand competition between powertrains & market niches



Segmentation

Vehicles
- Numbers, classes, drive-train mixes

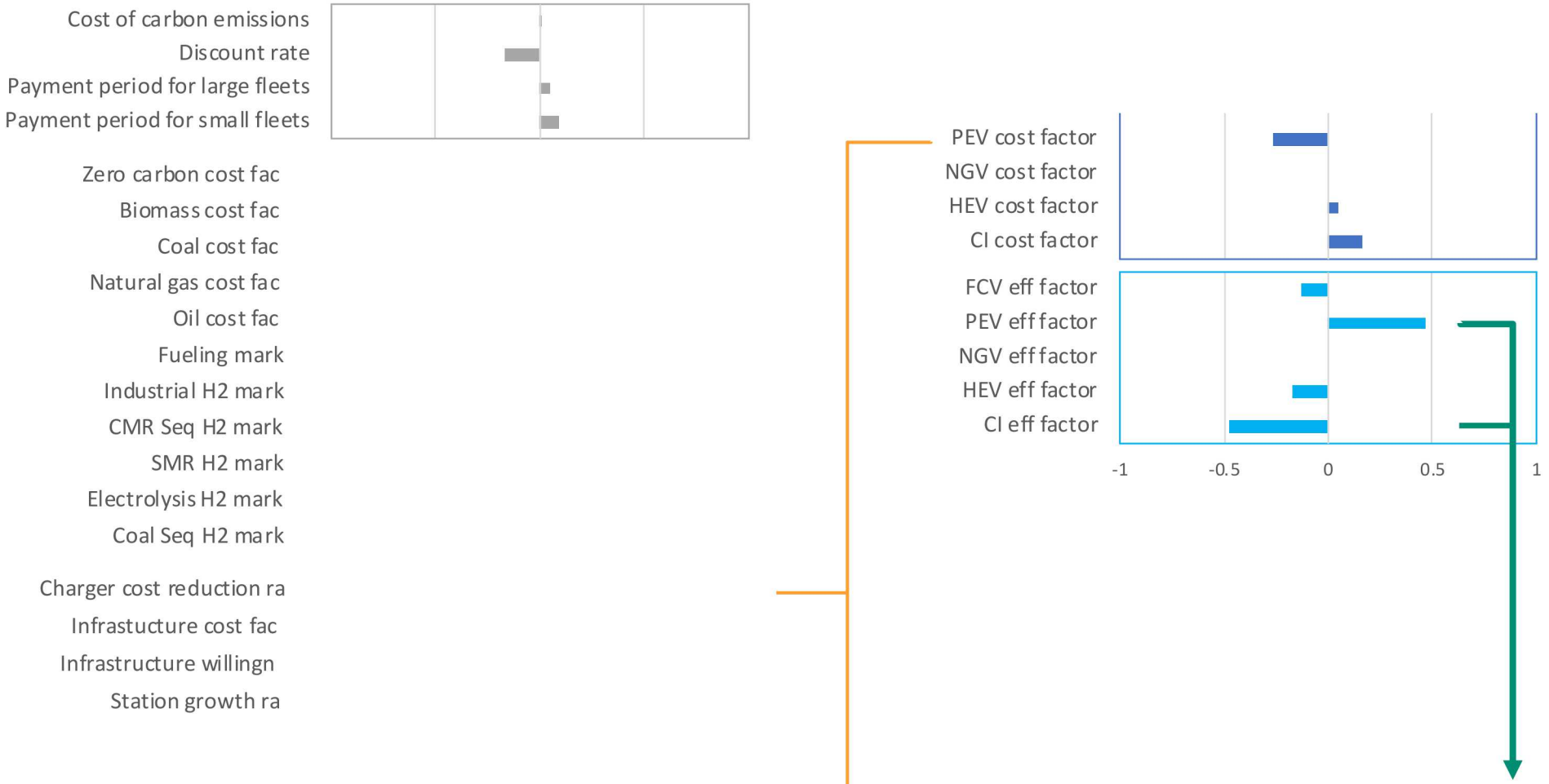
Service demographics
- Ton-mileage

Fuels
- Costs, electricity mix, hydrogen production pathway, taxes & fees, alternative fuel infrastructure

Energy supply curves (as appropriate)
- Oil, coal, natural gas, renewable electricity

Policy
- Consumer subsidies and incentives

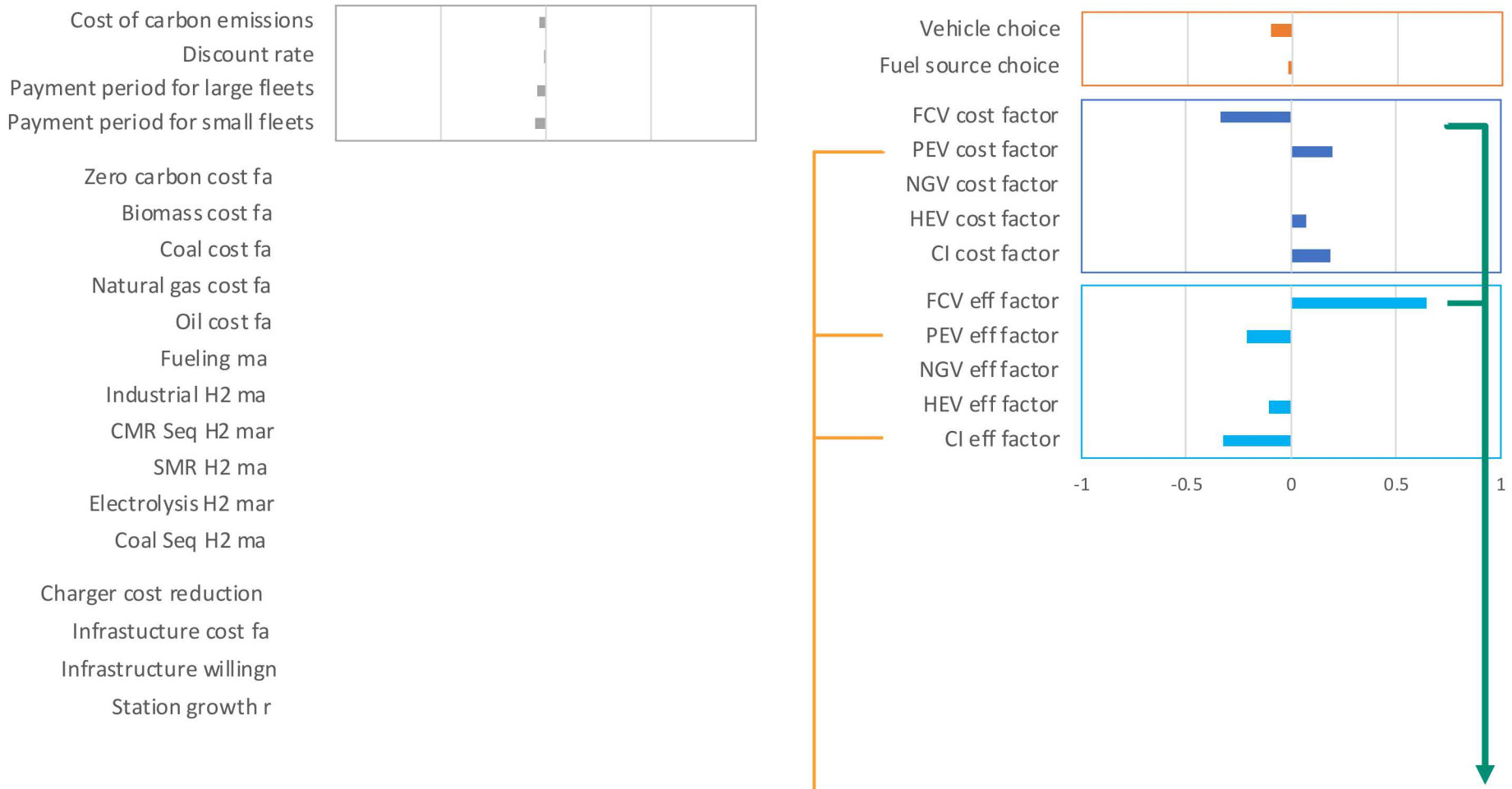
Sensitivity of PEV adoption (Spearman correlation shown)



Of all parameters varied, PEV adoption is most affected by own efficiency and the competing CI efficiency, highlighting the significance of fuel cost on choice.

Similarly impactful are the initial PEV purchase price and the charger cost reduction rate.

Sensitivity of FCEV adoption (Spearman correlation shown)



Of all parameters varied, FCEV adoption is most affected by FCEV efficiency and cost.

Similarly impactful are CI efficiency and PEV efficiency (& cost), highlighting influence of competition.

Modeling Approach – Model inputs are taken from published sources when possible, and many are parameterized

Energy sources

Oil: Global price EIA Annual Energy Outlook (2018)

Coal: National price EIA AEO (2018)

NG: Regional price EIA AEO (2018)

Biomass: State supply curves ORNL's Billion Ton Study

- Price corrected to match current feedstock markets

Fuel conversion and distribution

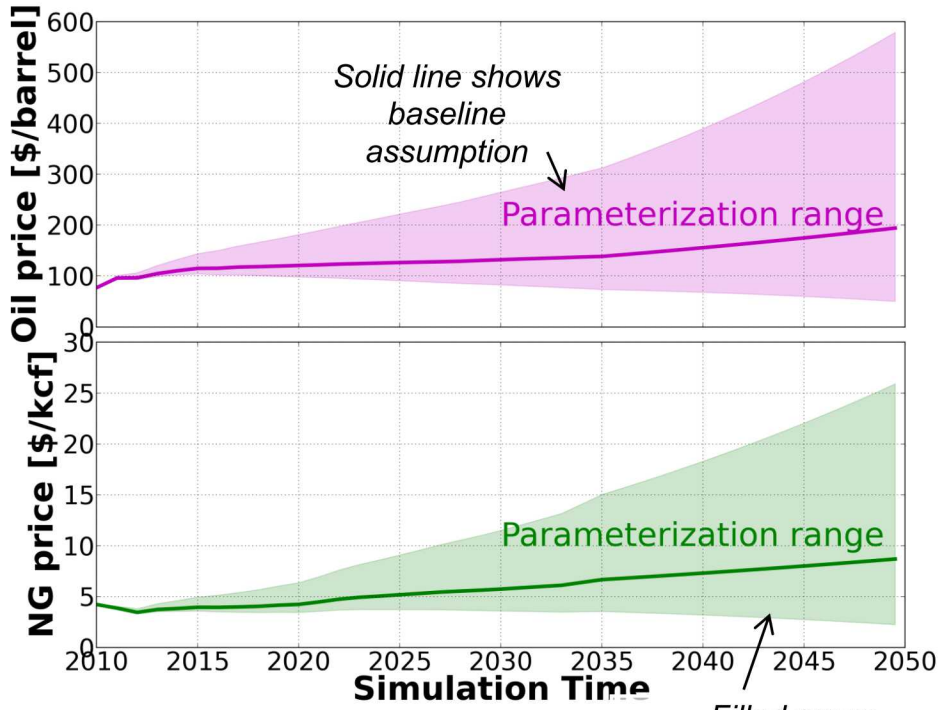
Conversion costs and GHG emissions derived from ANL GREET model

Electricity grid

- State-based electricity mix, allowed to evolve according to population growth and energy costs
- Intermittent and "always-on" sources assumed to supply base load first
- Vehicles assumed to be supplied by marginal mix

Hydrogen production

- Production cost based on least-cost pathway
- Production capacity allowed to evolve according to demand



Reviewer Only Slides

Publications

Levinson, R. S., & West, T. H. (2018). **Impact of convenient away-from-home charging infrastructure**. *Transportation Research Part D 65,* pp. 288-299.

Levinson RS, Manley DK & West TH. (2016). History v. Simulation: An analysis of the drivers of alternative energy vehicle sales. *SAE*, *Int. J. Alt. Power 5(2)*

Askin AC, Barter GE, West TH & Manley DK. (2015). The heavy-duty vehicle future in the United States: A parametric analysis of technology and policy tradeoffs. *Energy Policy*, 81, 1-13.

Barter GE, Tamor MA, Manley DK & West TH (2015). Implications of modeling range and infrastructure barriers to battery electric vehicle adoption. *Transportation Research Letters*, 2502, 80-88

Peterson MB, Barter GE, West TH & Manley DK. (2014). A parametric study of light-duty natural gas vehicle competitiveness in the United States through 2050. *Applied Energy*, 125, 206–217.

Barter GE, Reichmuth D, West TH & Manley DK. (2013) The future adoption and benefit of electric vehicles: a parametric assessment. *SAE Int. J. Alt. Power*, 6(1).

Westbrook J, Barter GE, Manley DK & West TH. (2013). A parametric analysis of future ethanol use in the light-duty transportation sector: Can the US meet its Renewable Fuel Standard goals without an enforcement mechanism?. *Energy Policy*, 65, 419-431.

Barter GE, Reichmuth D, Westbrook J, Malczynski LA, West TH, Manley DK, Guzman KD, & Edwards DM. (2012). Parametric analysis of technology and policy tradeoffs for conventional and electric light-duty vehicles. *Energy Policy*, 46(0), 473 – 488.

Critical Assumptions and Issues

Rational Consumers

- Empirical evidence suggests that the factors effecting vehicle purchase are complex and go beyond the purchase and operation costs of a vehicle. In the LDV segment color, brand preference, and social factors, among others, may influence a consumer to make an “irrational choice”, I.E. one that is not in their best financial interest. We are limited to modeling consumers that make choices that are bounded by cost.

Complexities of profit maximization

- In the heavy-duty segment, fleet operators work on narrow margins which are often unique to their specific vocation and location. To create a model that captures national level trends individual circumstances cannot and are not modeled. We assume that the effect of these unique circumstances on adoption and related quantities of interest is negligible at the national level.

Total Cost of Ownership (TCO)

- The actual TCO for a vehicle encompasses much more than purchase and fuel costs. The results of the VTO-Analysis-led TCO deep-dive; capturing the nuances of vehicle ownership is expected to have some effect on adoption projections.

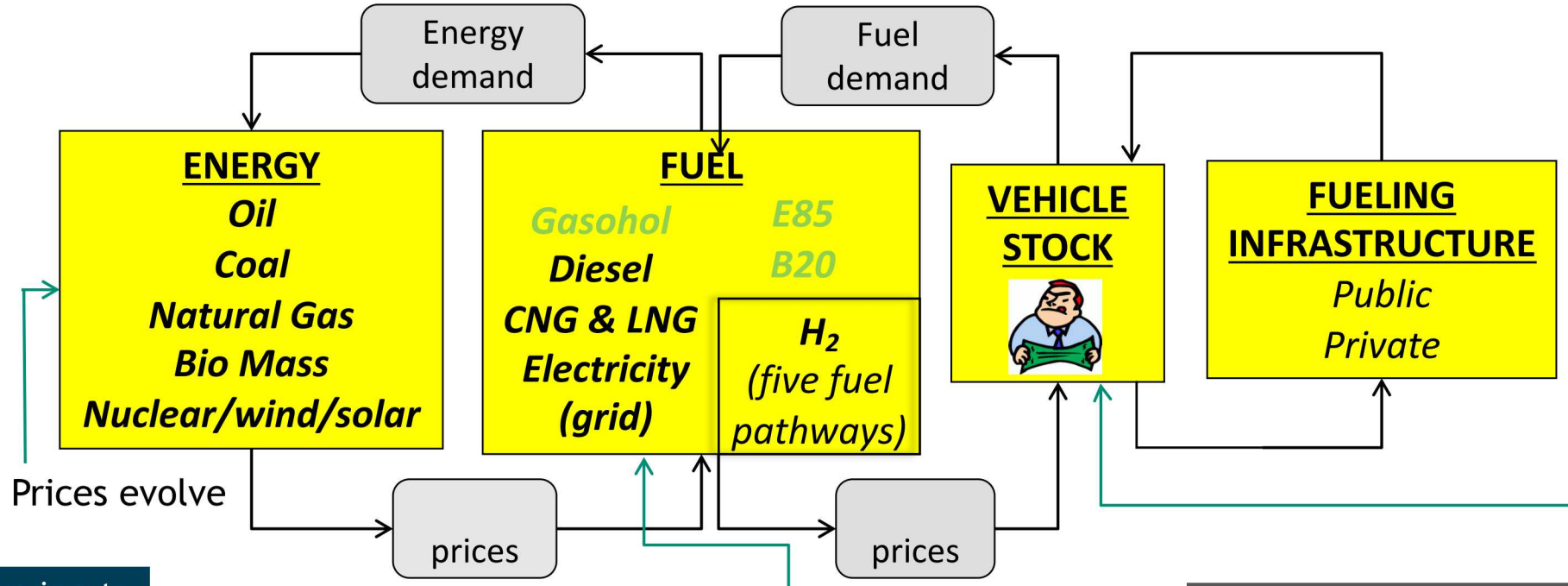
Acronyms

Acronym	Meaning
AF	Alternative Fuel
BE	Battery Electric
CI	Compression ignition
CNG	Compressed Natural Gas
FC/FCE	Fuel Cell/ Fuel Cell Electric
HD	Heavy-Duty
HE	Hybrid Electric
ISG	Integrated Starter Generator (Mild Hybrid)
LD	Light-Duty
LNG	Liquid natural gas
PE	Plug-in Electric
PHE	Plug-in Hybrid Electric
SI	Spark ignition
V	Vehicle

Approach: ParaChoice – Underlying systems model between energy and vehicles

Begins with today's energy, fuel, and vehicle stock and projects out to 2050. At each time step, vehicles compete for share in the stock based on value to consumers.

Green text is relevant for LD only



Parameters as $f(t)$:

- Veh. costs & efficiencies
- Model availability
- Stock size
- Powertrain prevalence
- Emissions

Baseline inputs

- Energy prices: AEO 2018
- Emissions: GREET
- Fleet segmentation: NHTS (LDV); Polk (HDV)
- VMT: FWHA, AFDC
- Vehicle price and performance: Autonomie; National Petroleum Council (HDV); NAP Phase 2
- Fueling stations: AFDC
- Policies (by state): AFDC

Policy options as $f(t)$:

RFS, carbon taxes, H_2 production pathways, electric grid composition

Red = endogenous

Variety of Output Options, Including:

- Sales Fractions
- Vehicle Stock
- Emissions
- Fuel Consumption
- Trades & Sensitivities