SAND2017-3625PE

Heavy-Duty Vehicles Analysis with the Sandia ParaChoice Model

Project ID#: VAN019

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Sandia National Laboratories

DOE Annual Merit Review, June 8th, 2017

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

Overview

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Timeline and Budget

- Start date: FY14
- End date: Project continuation determined annually
- FY14 VTO Budget: $80k
- FY15 VTO Budget: $150k
- FY16 VTO Budget: $350k
- FY17 VTO Budget: $350k
- FY17 funds received*: $194k
- FY17 funds spent*: $127k

*as of 3/31/2017

Barriers

A. Availability of alternative fuels and electric charging station infrastructure
   - Lack of fueling infrastructure to compete with the fully mature conventional petroleum-based fuels
   - Few electric charging stations needed for the coming plug-in hybrid electric vehicles (PHEVs) and fully electric vehicles (EVs)

B. Availability of AFVs and electric drive vehicles
   - OEM supply limitations for technologies such as CNG
   - Cost limitations for technologies such as PHEVs

C. Consumer reluctance to purchase new technologies
   - Uncertainties in value proposition for OEMs & buyers

Partners: Interactions / Collaborations:

- Ford: Real World Driving Cycles
- Toyota
- American Gas Association
- DOT
- ANL, ORNL, NREL, LBNL, Energetics
- North American Council for Freight Efficiency (NACFE)

Relevance & Objective: Parametric analysis to understand factors that influence vehicle, fuel, & infrastructure mix

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- *Lifetime project goals*: Understand changes to both the Light and Heavy Duty Vehicle (LDV & HDV) stock, fuel use, & emissions, including BEV and PHEV ← Addresses barrier A
  - System level analysis of dynamic between vehicles, fuels, & infrastructure
  - Use parametric analysis to
    - Identify trade spaces, tipping points & sensitivities
    - Understand & mitigate uncertainty brought in by data sources and assumptions
- *HDV*: Added model capability to handle vocational HDVs
  - Evaluating how AFVs can increase HDV freight hauling efficiency & reduce pollution

  [New FY17 Analysis; Addresses VTO Goal]
- *LDV*: Determine the impact of both public and workplace EV charging infrastructure on EV adoption and use ← Addresses barriers A & C
  - Scenario analysis for level 2 and DC fast public charging stations
    - Baseline scenario
    - Three scenarios with level 2 or DC fast station injection (incl. e^- surcharge)
  - Parametric analysis for public charging infrastructure
    - DC fast chargers injected nationally
    - DC fast chargers injected in 10 states with a ZEV mandate
    - DC fast chargers injected only in California in 2017

  [Follow up on 2016 AMR preliminary results; Submitted for publication to *TRANSPORT RES D-TR E*]
  - Parametric analysis for workplace charging
    - Monte Carlo uncertainty analysis (people vs. miles; access vs. range)
- *Updates*: AEO 2016, Moawad *et al.*, and GREET 2016

  [New FY17 Analysis]

Milestones

Date	Milestones and Go/No-Go Decisions	Status
December 2016	*Milestone* Complete parametric sensitivity study of charging infrastructure availability for discussion with DOE/VTO	Complete
Mar 2017	*Milestone* Solicit feedback on LDV parametric sensitivity study and refine accordingly summarize feedback and proposed refinement to HQ	Complete
June 2017	*Milestone* Compose journal article based on parametric sensitivity study	On track pending funding
June 2017	*Go/No-Go Decision* Assess project for meeting DOE criteria for 1) solving a long-term, difficult challenge, 2) providing a unique capability, and 3) being relevant to the EERE mission.	On track
September 2017	*Milestone* Develop online interface to selected model results	On track

Approach: ParaChoice – Underlying systems model between energy and LD or HD vehicles

Marches forward from present, when energy, fuel, and vehicle stock states known, to 2050. At each time step, vehicles compete for share in the stock based on value to consumers.

Energy demand

Fuel demand

ENERGY
Oil
Coal
Natural Gas
Bio Mass
Nuclear/wind/solar

FUEL
Gasohol
Diesel
CNG & LNG
Electricity (grid)
E85
B20
H_2 (five fuel pathways)

VEHICLE STOCK

Vehicle costs & efficiencies, model availability, infrastructure evolution, stock size, stock powertrain composition, and stock emissions vary in time

Red values are endogenously simulated

Prices evolve

Energy prices

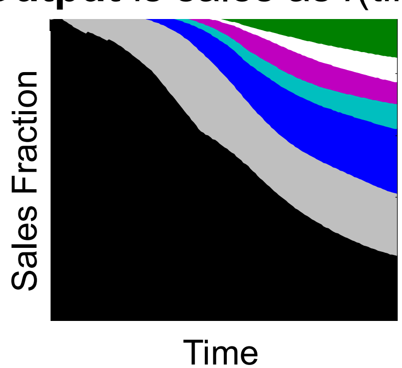
Fuel prices

Baseline inputs

- Energy prices: AEO 2016
- Emissions: GREET
- Fleet segmentation: NHTS (LDV); Polk (HDV)
- Vehicle price projections: Autonomie (LDV); National Petroleum Council (HDV)
- 2010-2017 fueling stations: AFDC
- Policies (by state): AFDC

RFS, carbon taxes, H_2 production pathways, electric grid composition, all vary in time

Output is sales as *f*(time)



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

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VEHICLE STOCK

Vehicle		Generalized Vehicle Cost
Conv. SI	→	$X /year
FCEV	→	$Y /year
PHEV40	→	$Z /year

… And 17 more

Given:
- Input attribute(s)
- Fixed set of 2+ output choices

Nested Multinomial Logit Function

Outputs:
- Probability distribution

Percent of Sales
A %
B %
C %

Generalized Vehicle Cost

Upfront Costs Amortized Over "Required Payback Period"

- Purchase price
- One time incentives
- One time penalties *(Infrastructure penalty)*

Recurring Costs

- Fuel cost
- Annual incentives
- Annualized penalties *(Range penalty)*

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

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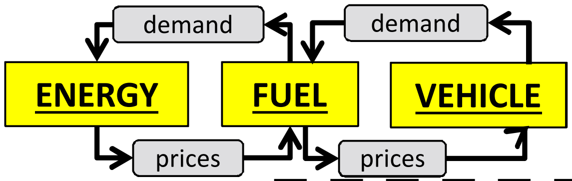

Demographics | *Vehicle* | *Geography*

LDV Segmentation

Powertrain
20 Powertrains

Housing type
With or w/o access to charging/ fueling

Driver Intensity
Low, Med, or High

VMT Segmentation

Energy/Fuel Seg.

State
48 CONUS + Washington, DC

Density
Urban
Suburban
Rural

Size
5 Sizes

Age
0-46 years

HDV Segmentation

Powertrain
CI (4 Types)
CNG (3 Types)
LNG (2 Types)

Refueling Type
Gas Station
Truck Stop
Private

Age
0-18 years

GVW
Class 7 & 8

Body Type
Tractor Trailer
Straight Truck
Bus

(Vocation)
Construction
Food
General Freight
Lease/ Finance
Manufacturing
Natural Resources
Services
Wholesale/Retail

Fleet Size
1-9; 10-99; 100-999; 1,000+

State
48 CONUS + Washington, DC

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

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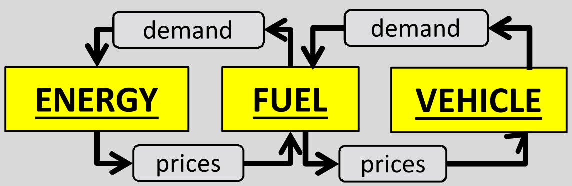
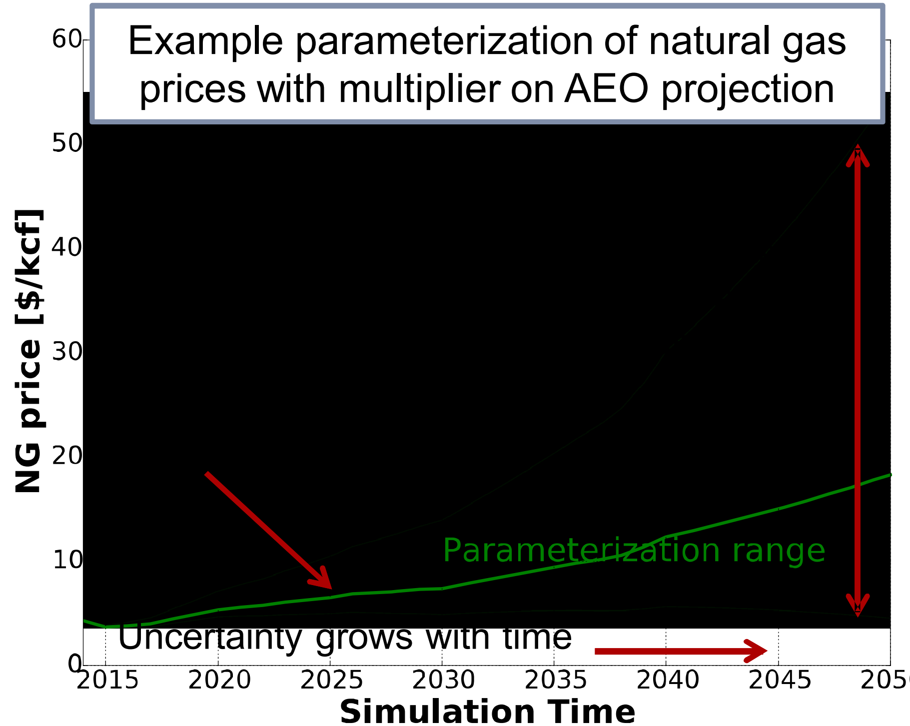
***Uniqueness from other DOE models*:**
ParaChoice is designed to explore uncertainty & trade spaces, easily allowing identification of tipping points & sensitivities

- Core simulation is a system-level analysis of dynamic, economic relationship between energy, fuels, & vehicles with baseline values from trusted DOE sources. Technologies compete in the simulation, are allowed to flourish or fail in the marketplace.



- Simulation is run 1000s of times with varying inputs. This parametric analysis provides:
  - 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



- Vary two parameters at once- trade space analysis (~400 scenarios)
- Vary many parameters- sensitivity analysis (~3000 scenarios)
- Parameterization ranges designed to explore plausible AND 'what if' regimes, covering all bases

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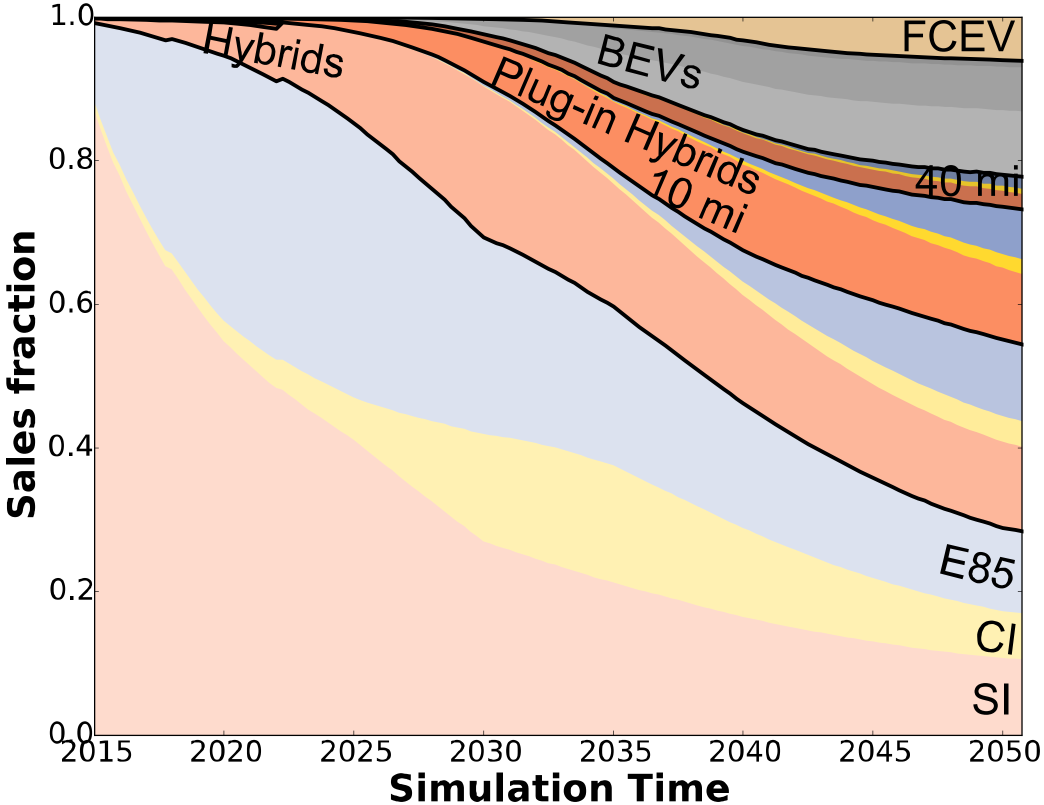
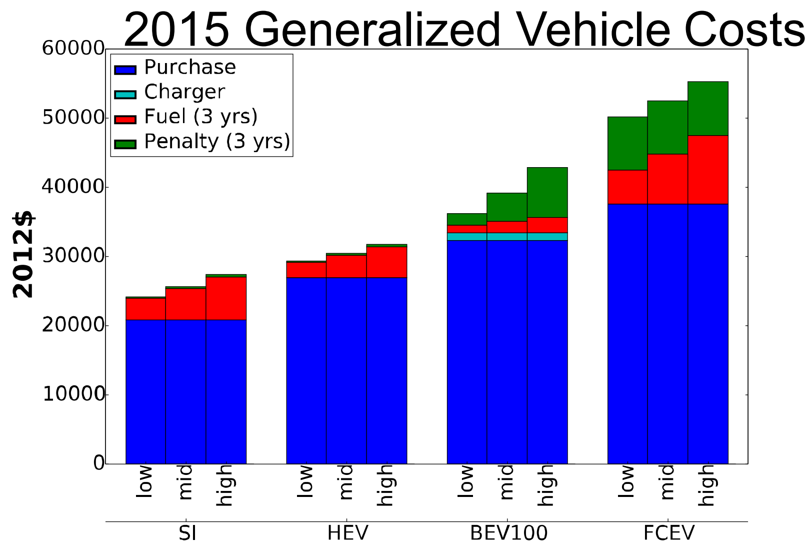
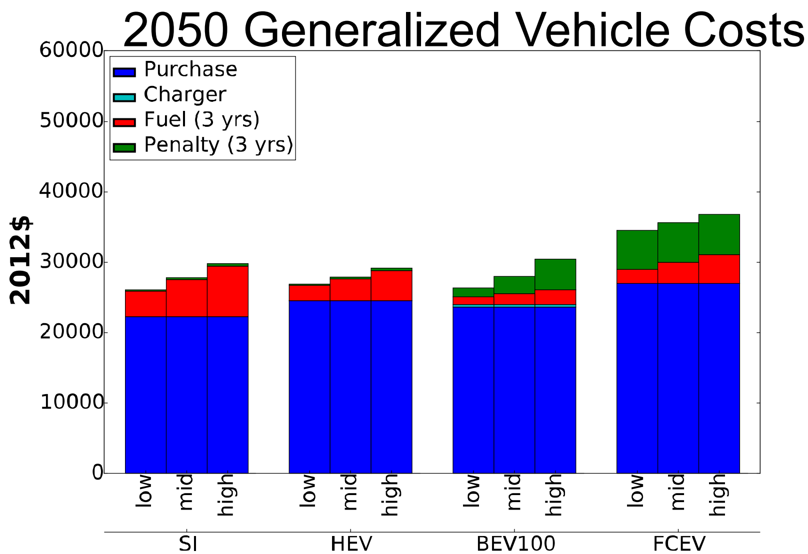
Business as Usual Projection





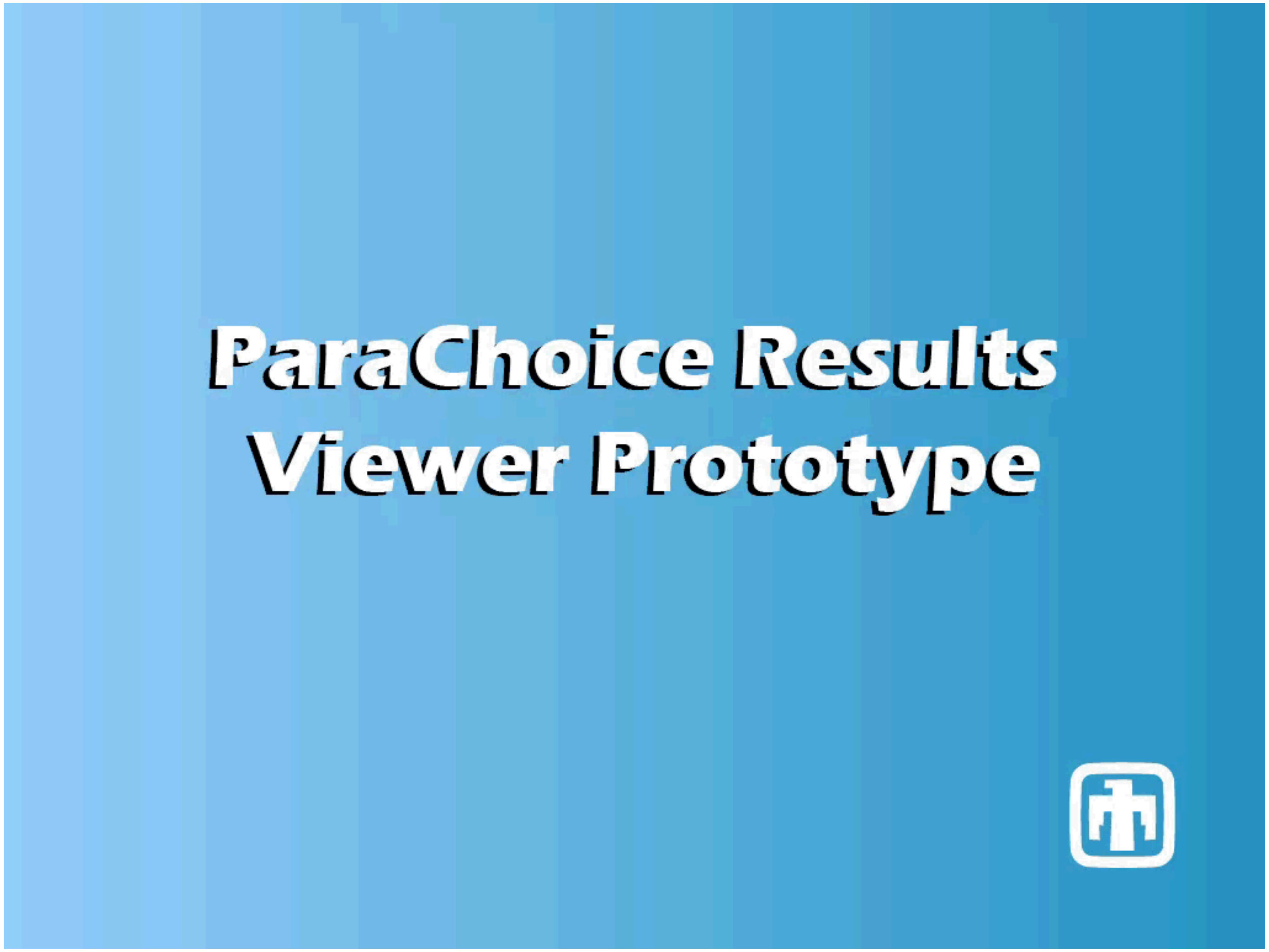


Key results:

Modest penetration of BEV 75, 100, & 200 (~14%) by 2050 due to decreases in BEV purchase cost and fuel cost advantage to petrol.

Scenario projections are NOT the goal of the model, but a starting point for understanding market drivers

Accomplishments & Progress: Results Viewer and Baseline Results



A&P Public Charging 2: Station injection scenarios show impact on BEV sales and electrified mileage

Powertrain	Baseline (%)	500K Level 2 (Δ%)	50K DC Fast (Δ%)	50K DC Fast + 10¢/kWh Elec. Surcharge (Δ%)
Conventionals	29	-1	-2	0
Hybrids	26	0	-1	+1
Plug-in Hybrids	24	-1	-3	-1
BEVs	16	+1	+7	-1
FCEV	6	0	-1	0
% of All Fleet Miles Electrified	15	+1	+8	+1

Absolute and baseline #s are not important; insights come from Δs with changes in assumptions

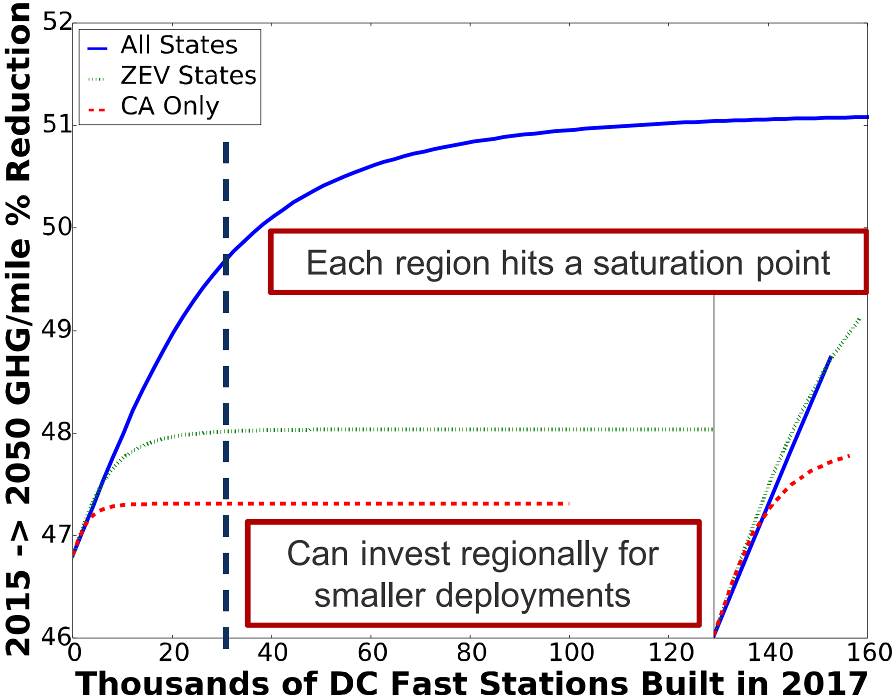
Level 2 charging does very little compared to DC fast.

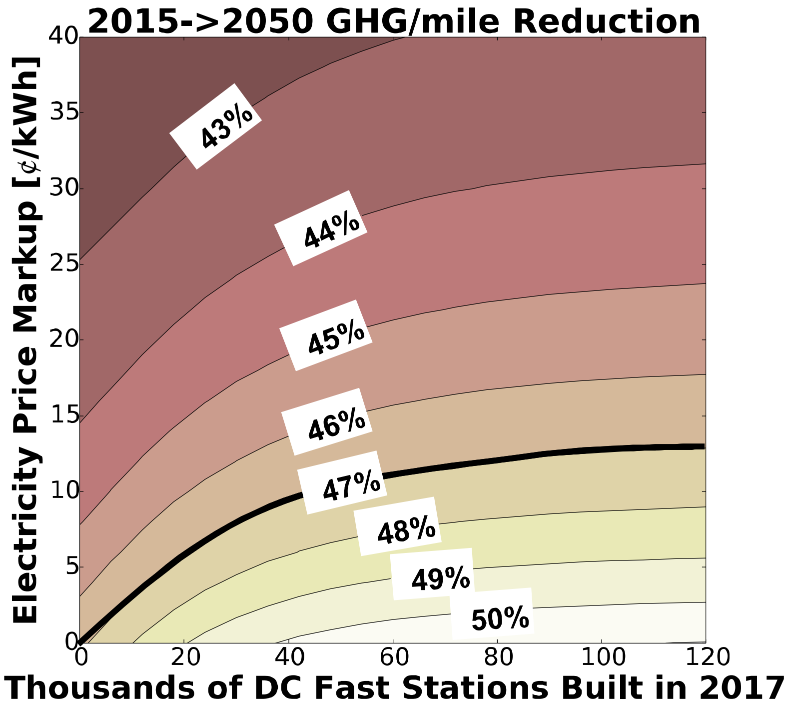
10¢/kWh elec. surcharge severely dampens sales and electrified mileage gains

Key results:

For large scale national deployment strategies, public DC fast chargers will be more effective than public level 2 chargers at increasing BEV sales, increasing electrified mileage, and lowering GHG emissions, even if only one DC fast charging station is built for every ten level 2 charging stations

A&P Public Charging 3: Charging infrastructure emissions savings and cost transfer to EV owners





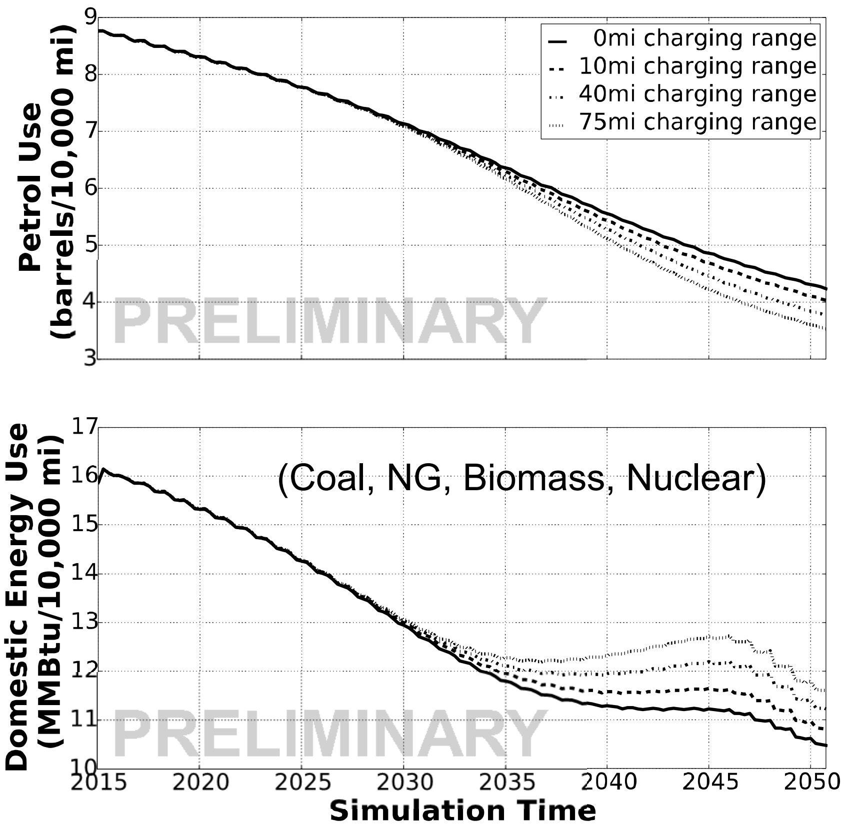
Key results:

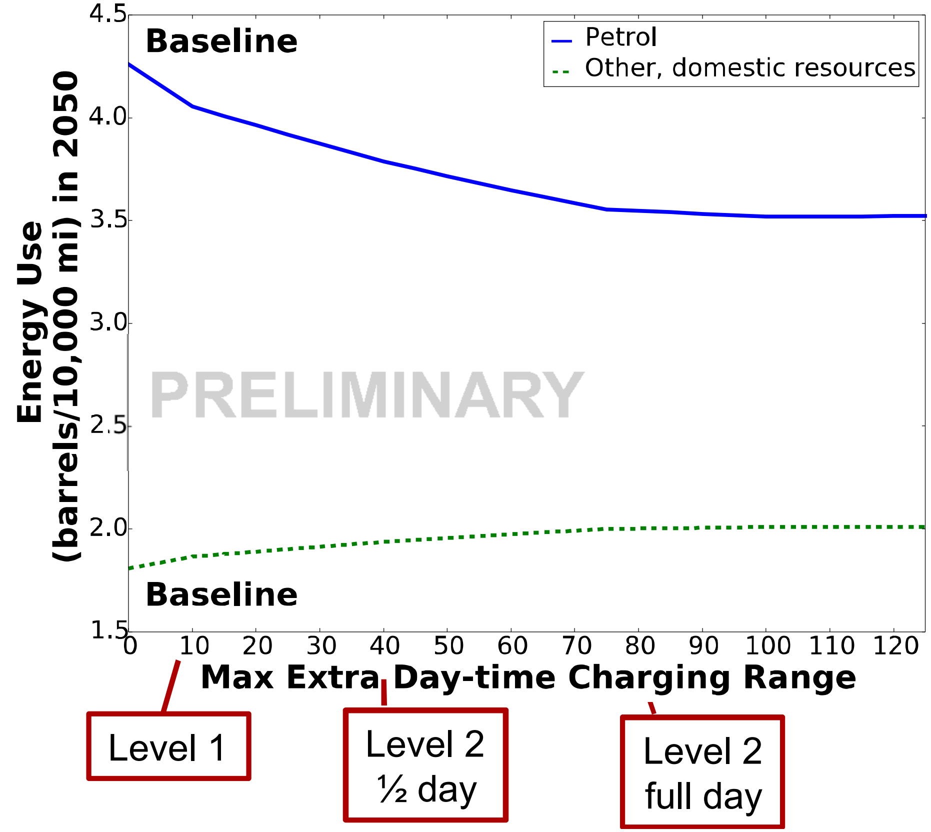
1. Nationally, we may begin to see diminishing ROI for DC fast EV infrastructure at 30K stations. We currently have 2K DC fast stations with 5.1K outlets.
2. Some costs may be passed on to EV owners, but the total effective surcharge should be kept to less than 12¢/kWh or the benefits of the infrastructure may be lost.

A&P Workplace Charging 1: Energy savings for convenient charging

Analysis Strengths

1. Incorporating and analyzing DOE strategies for targeted infrastructure at the workplace
2. Recognizing the potential weaknesses of traditional infrastructure models for AEVs
3. Monte Carlo analysis to understand limitations of assumptions & confidence in trends.





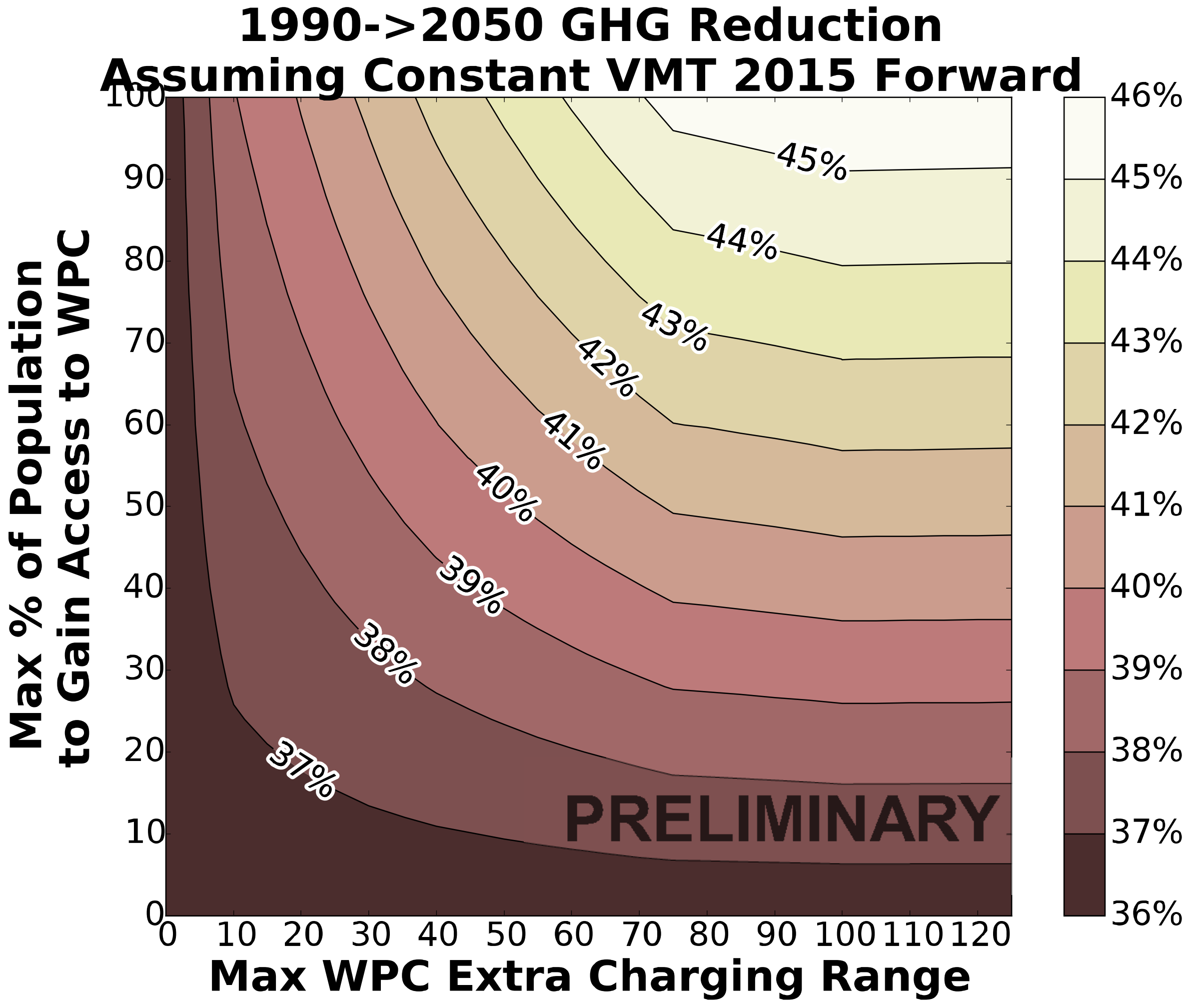
Key Result

As we increase the day-time charging range that is conveniently & reliably available to the population, fleet-wide petrol use will drop in favor of other, purely domestic resources.

A&P Workplace Charging 2: Workplace charging accessibility versus range tradespace analysis

Analysis strengths

1. Fraction of population with access to workplace charging is an evolving, parameterizable, modeling segment.
2. Tradespace analysis informs policy decisions

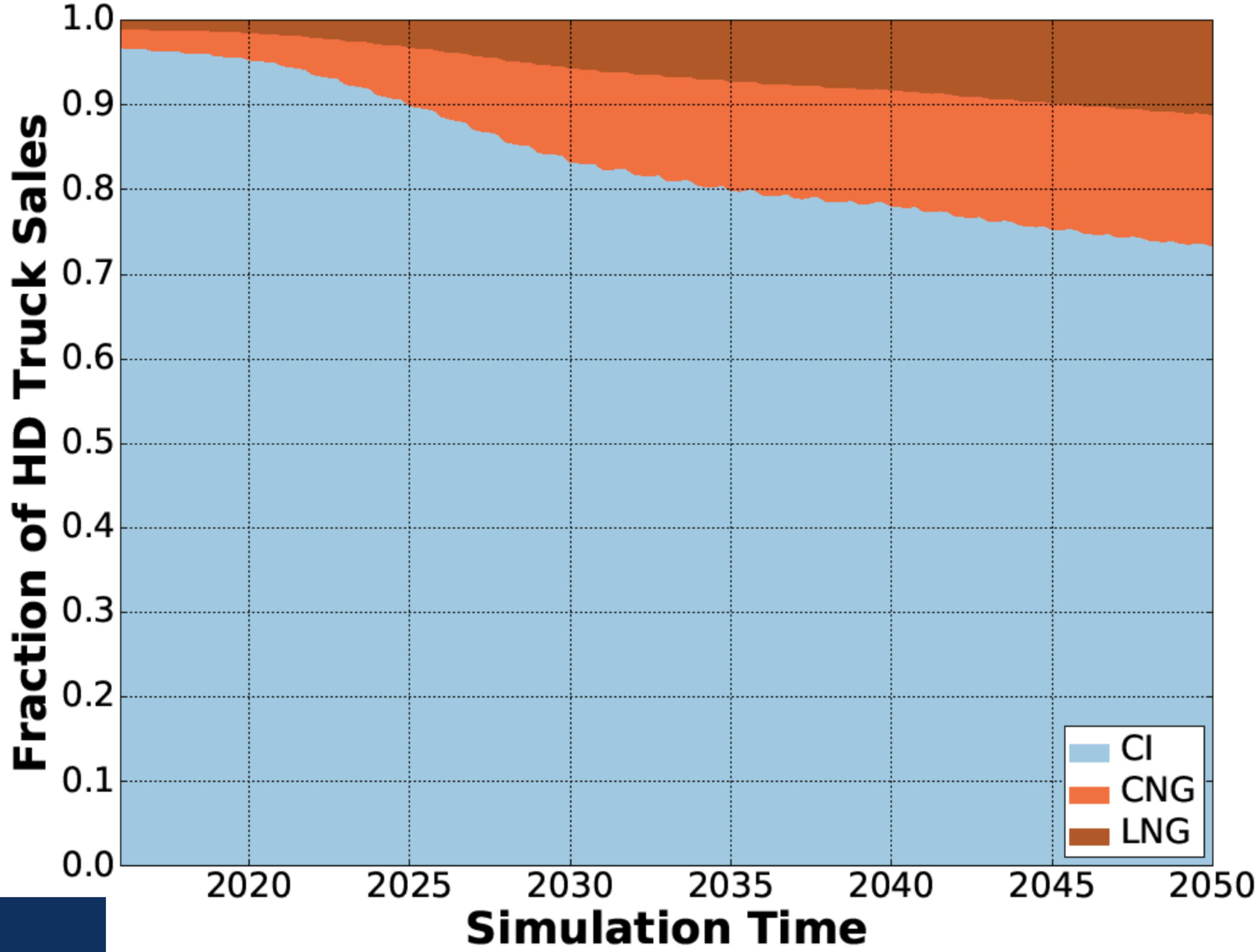


Key Result

A large percent of the population needs access to reliable level 2 workplace charging in order to significantly reduce GHG emissions by 2050. Even with 100% penetration, the LDV fleet falls short of 80% reductions by 2050.

A&P HDV Analysis 1: Natural gas incentives only subtly impact heavy-duty vehicle powertrain adoption

- Baseline: Approx. 1/4 HDVs are NG powered
- No change with $0.50 incentive through 2016
- NGV fraction incr. to 1/3 with 2050 incentive
- "Free" NG fuel is required to incr. fraction to >0.50
- Growth is primarily in LNG vehicles



Without NGV Incentive

Key Result
Practical NGV incentives have minimal impact on adoption

A&P HDV Analysis 2: ParaChoice model and data updates to assess impacts of new technologies for Class 7 & 8 HDVs

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ParaChoice *model* updated to greatly simplify adding new, user-specified segments/vocations

Collected *data* on Class 7 & 8 HDV segmentation & vocations
- Vehicle Count
- Vehicle Miles Traveled (VMT)
- Fuel Consumption

- **Class 7 & 8**
  - **Tractor Truck + Gliders (126,000)**
    - **Short Haul (50,000)**
      - **Drayage**
      - **Delivery**
      - **Refrigerated Truck**
    - **Long Haul (76,000)**
      - **Semi- and sleeper-semi**
        - **Refrigerated Truck**
        - **Non-Refrig. Truck**
  - **Straight Truck (147,000)**
    - **Short Haul (132,000)**
      - **Delivery**
        - **Refrigerated Truck**
        - **Non-Refrig. Truck**
    - **Long Haul (15,000)**
  - **Bus (44,000)**
    - **Transit (4,000)**
    - **School (40,000)**
  - **Specialized (31,000)**
    - **Sanitation/Refuse Truck (9,000)**
    - **Fire Truck (6,000)**
    - **Motor Home (9,000)**
    - **Bucket/Utility Truck (7,000)**

Key Result

Only some segments are appropriate for new technologies based on count or duty cycle

Data: Polk 2013

A&P HDV Analysis 3: Alternative energy technology benefits depend on the HDV fleet and drive cycle characteristics

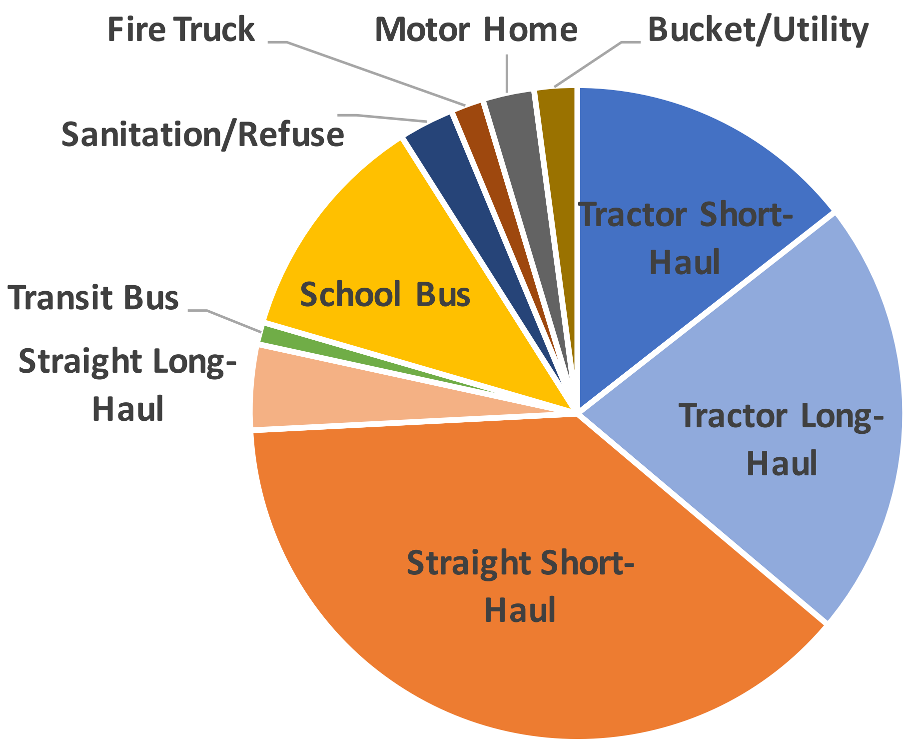
HDVs are significant contributors to air pollution (e.g. NO_x)

$$\begin{Bmatrix} Technology \\ Benefit \end{Bmatrix} = \begin{Bmatrix} Market \\ Size \end{Bmatrix} \times \begin{Bmatrix} Savings/ \\ Reduction \end{Bmatrix}$$

Market Size:
- Count
- VMT

Savings/Reduction:
- **Fuel Use**: Tractive effort, Idling, Vocational load
- **Pollutants**: NO_x, SO_x, PM

Alternative energy technologies impact one or more of these in different ways



The HDV fleet is heterogeneous

- Vocational HDVs are ~30% of market
- ~40,000-60,000 built per year
- 100s of unique applications → small sales volume for each application
- Most OEMs develop a common chassis rather than building 100+ unique

Collaborations

- No funding given to other institutions on behalf of this work
- Technical critiques received from Ford Motor Company, General Electric, American Gas Association, and other conference engagements
- The underlying ParaChoice model has been developed using funding from a variety of sources including
  - Sandia Laboratory Directed Research & Development Funds
  - Clean Energy Research Consortium
  - Vehicle Technologies Office
- Collaboration on BaSce, a cross-lab model comparison for baseline & DOE program success scenario cases, led by Tom Stephens (ANL)
- This work is complemented by modeling and analysis for the FCTO. Rebecca Levinson will be presenting on FCTO-funded ParaChoice analysis (project ID SA055) Thursday June 8 at 4:45 PM

Proposed Future Work

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- Market level analysis of vehicle component benefits in complement to ANL "Evaluation of Individual Vehicle Technologies Office Benefits on Standard Drive Cycles" } **Joint effort with ANL analysis team**
  - Assess the benefits of VTO vehicle component level research by determining the detriment of defunding DOE-supported research into individual vehicle technologies
    - Quantify the impact each technology has on US petrol consumption, energy expenditure, cost to consumers, and GHG emissions
  - Account for synergistic effects between individual vehicle technologies in showing the impact of cost cutting decisions on the technologies in the VTO portfolio
- Quantitatively characterize the fleet of HDVs on the road (count + drive cycle) to identify the potential for technology to improve fuel efficiency and air quality
  - Identify the "beachhead market(s)" where alternative energy technologies would provide the greatest benefit and commercial viability

Milestones:

Compose journal article for peer review by end of FY17 Q3

Develop online interface to selected model results by end of FY17 Q4

Any proposed future work is subject to change based on funding levels and direction from VTO program managers

Summary

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- ParaChoice
  - Is a **validated system level analysis model** of dynamic between vehicles, fuels, & infrastructure
    - **Leveraging other DOE models and inputs**
    - Simulating fuel production pathways that scales with fuel demand
  - Is **designed for parametric analysis** in order to
    - **Understand & mitigate uncertainty** brought in by data sources and assumptions
    - Identify trade spaces, tipping points & sensitivities
  - Helps us understand changes to the LDV and HDV stocks, fuel use, & emissions
  - Is NOT simply a tool for creating scenario sales projections

- Analysis key results:
  - Public Charging
    - Start to see diminishing ROI after deploying approximately 30K public DC fast chargers
    - Public DC fast charging infrastructure may increase fleet-wide electrified mileage by ~8%
    - No more than a 12¢/kWh total effective surcharge should be passed to EV drivers
  - Workplace Charging
    - Increasing the availability of daytime charging decreases petrol use and favors domestic energy
    - Much of the population needs access to level 2 workplace charging to significantly reduce GHGs
  - HDVs
    - Natural gas incentives only subtly impact HDV powertrain adoption
    - The HDV fleet is heterogeneous; vehicle count and drive cycle impact efficiency and emissions

- Future work will show the impact of VTO investments in component technologies on fuel consumption and emissions as well as the potential for alternative technologies for HDVs

Technical Backup Slides

Approach: How ParaChoice models infrastructure, or lack thereof

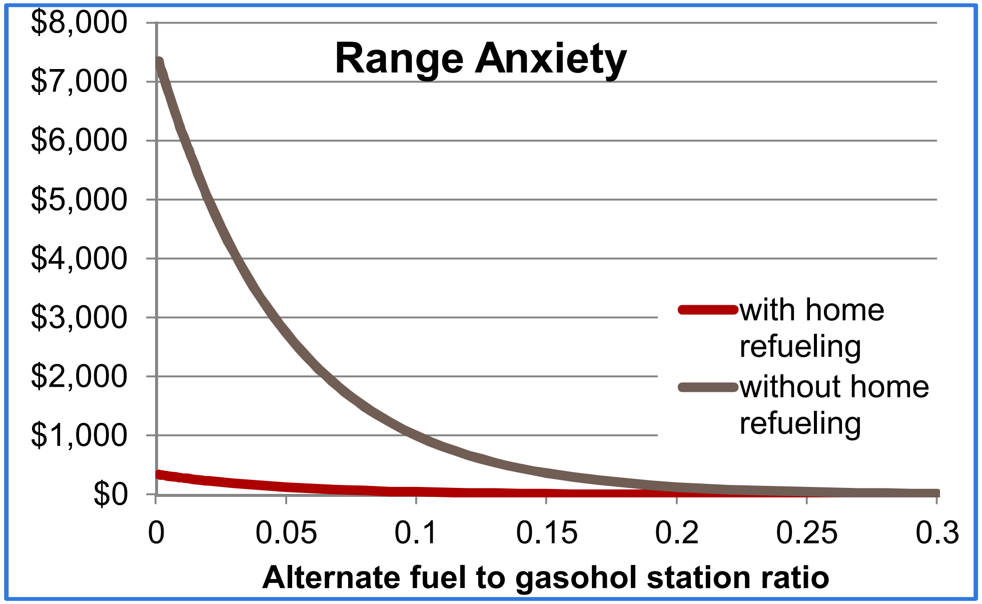
- For public infrastructure, charging outside of home is inconvenient. BEV drivers may opt to:
  - Use an alternate vehicle for long trip days[2]

    Penalty = $Rental vehicle cost *x* number of days driving beyond BEV range

OR

  - Use EV infrastructure, tolerating[1]
    - range anxiety due to station scarcity and
    - charging times

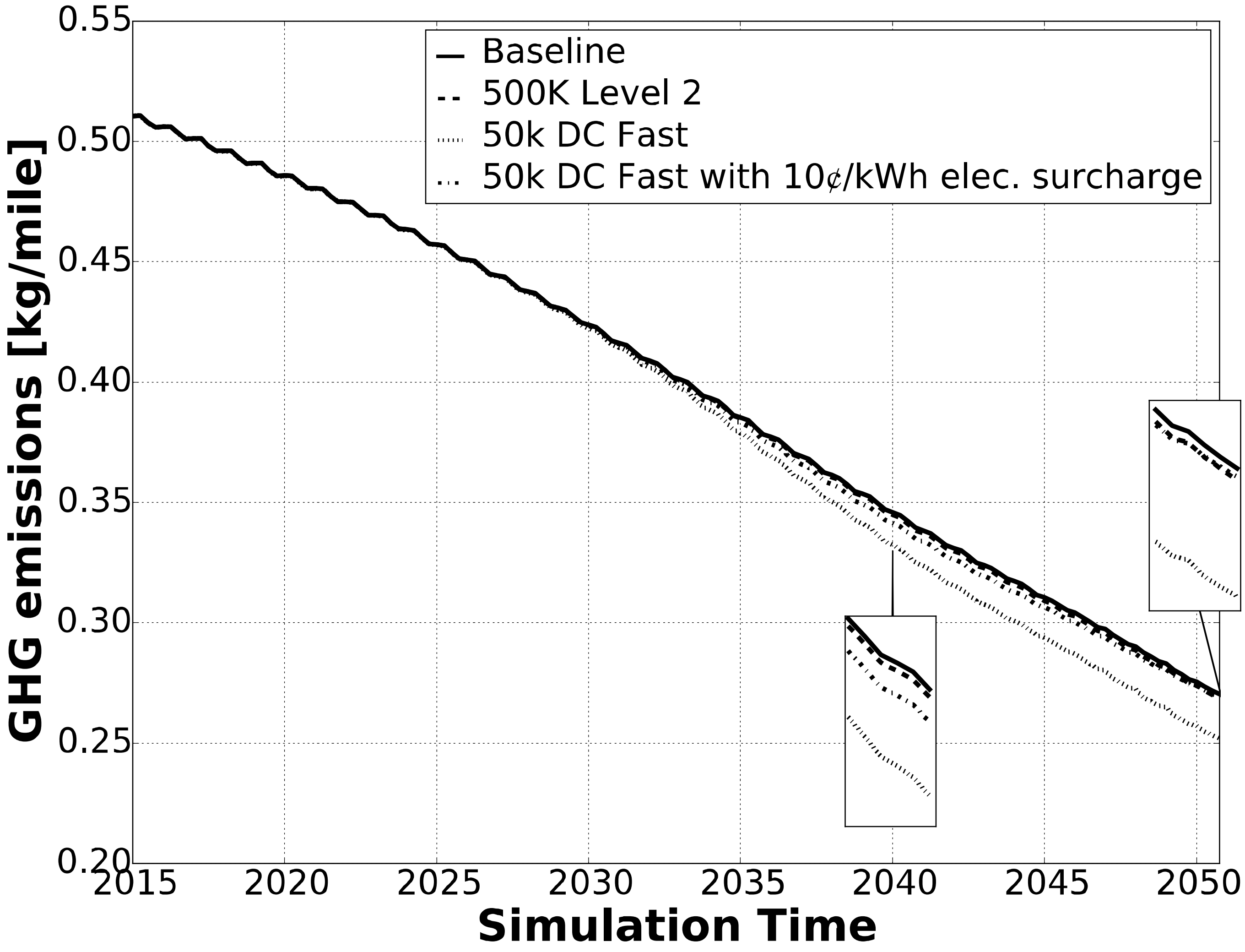
      Penalty = $Value of time *x* (hours refueling inconveniently)



- Workplace-type charging is convenient, and has different impacts
- No explicit monetization for EV infrastructure's beneficial impact on consumer 'awareness' of EVs

D. L. Greene. TAFV Alternative Fuels and Vehicle Choice Model Documentation. ORNL 2001.
G. E. Barter, M. A. Tamor, D. K. Manley, and T. H. West. *TRR Journal*, (2502):80–88, Sept. 2015.

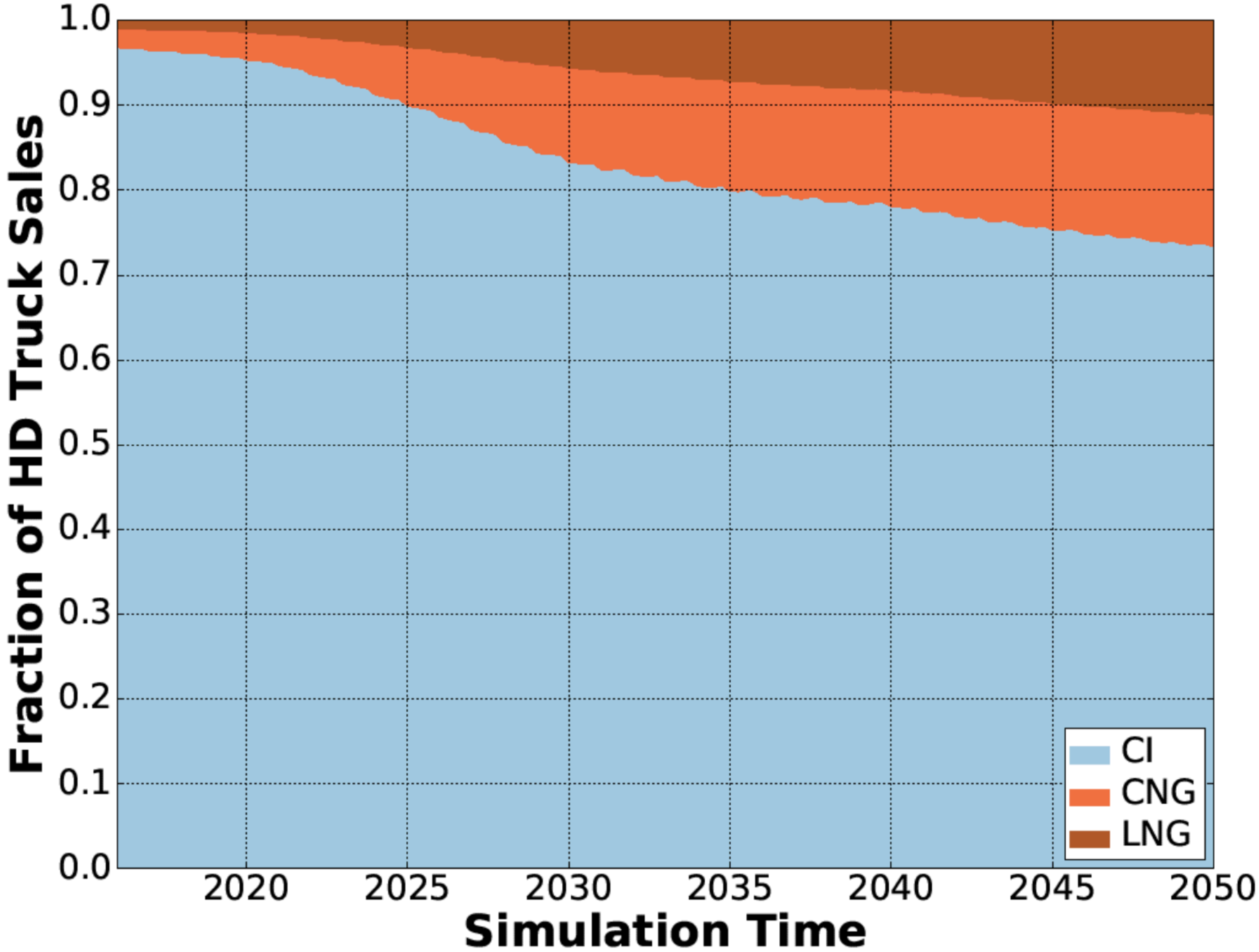
A&P Public Charging: GHG Emissions Impact



10¢/kWh electricity surcharge negates impact of public charging

A&P HDV Analysis 1: Natural gas incentives only subtly impact heavy-duty vehicle powertrain adoption

- Baseline: Approx. 1/4 HDVs are NG powered



Without NGV Incentive

A&P HDV Analysis 1: Natural gas incentives only subtly impact heavy-duty vehicle powertrain adoption

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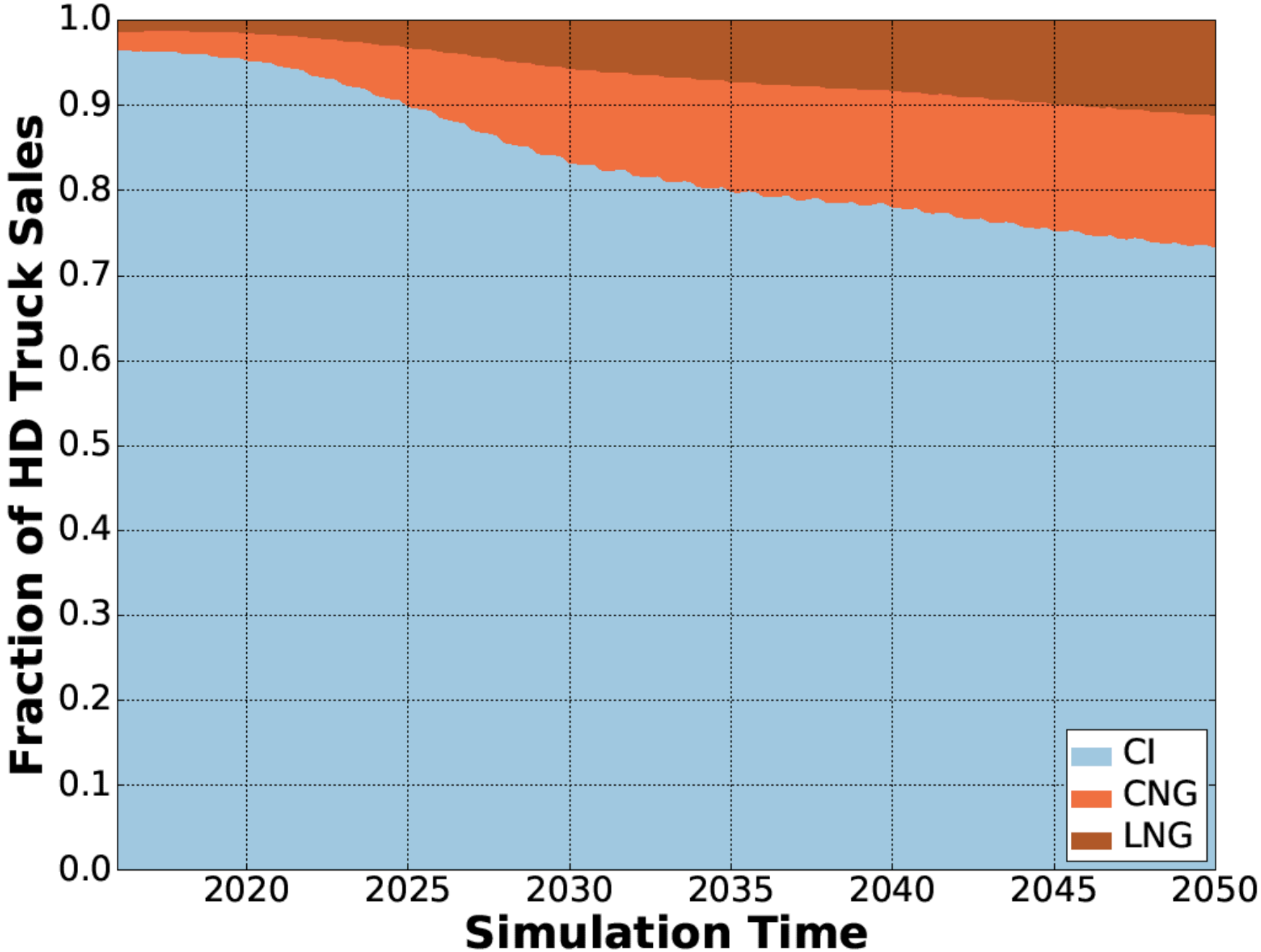
- No change with $0.50 incentive through 2016



$0.50 NGV Incentive Through 2016

A&P HDV Analysis 1: Natural gas incentives only subtly impact heavy-duty vehicle powertrain adoption

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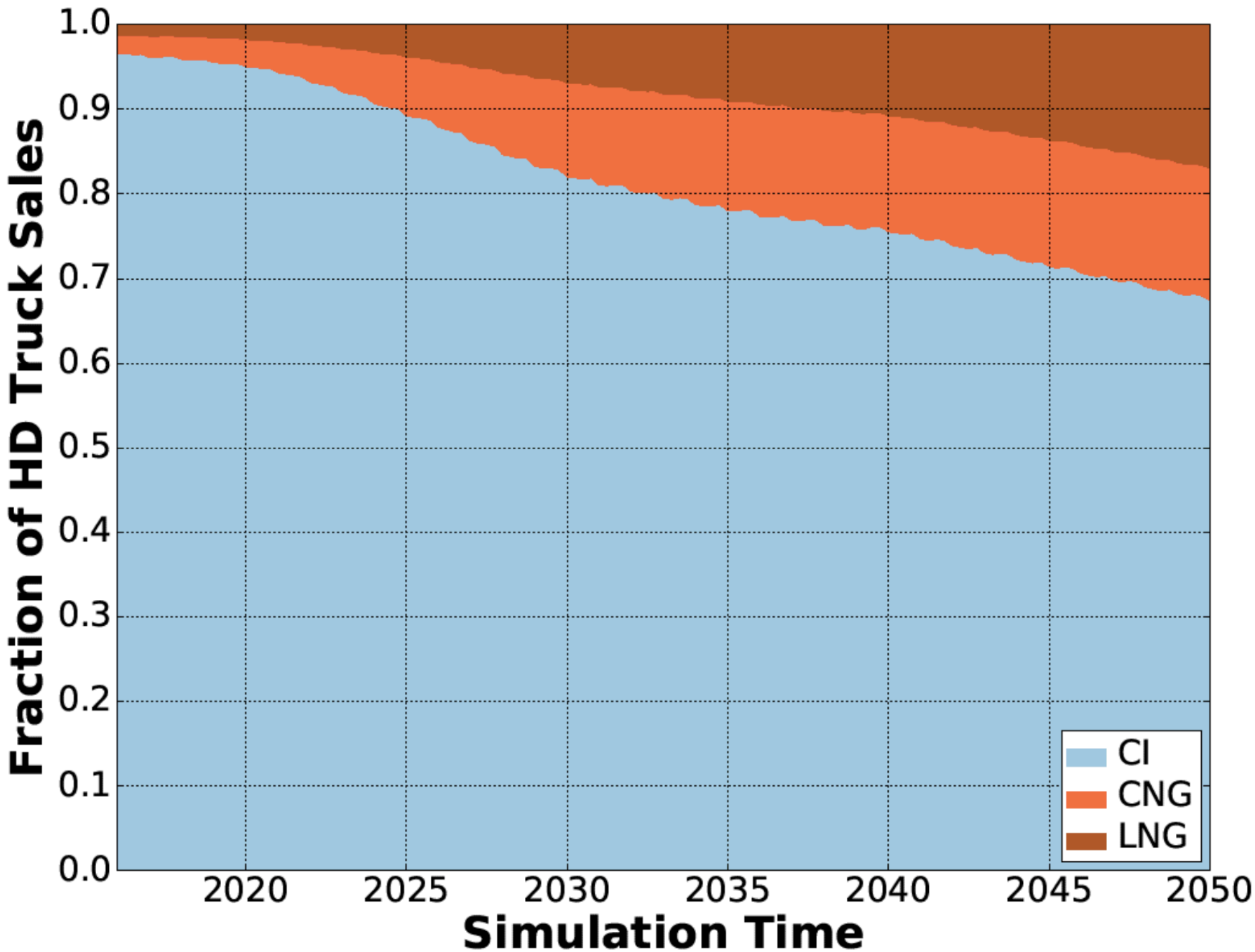

$0.50 NGV Incentive Through 2050

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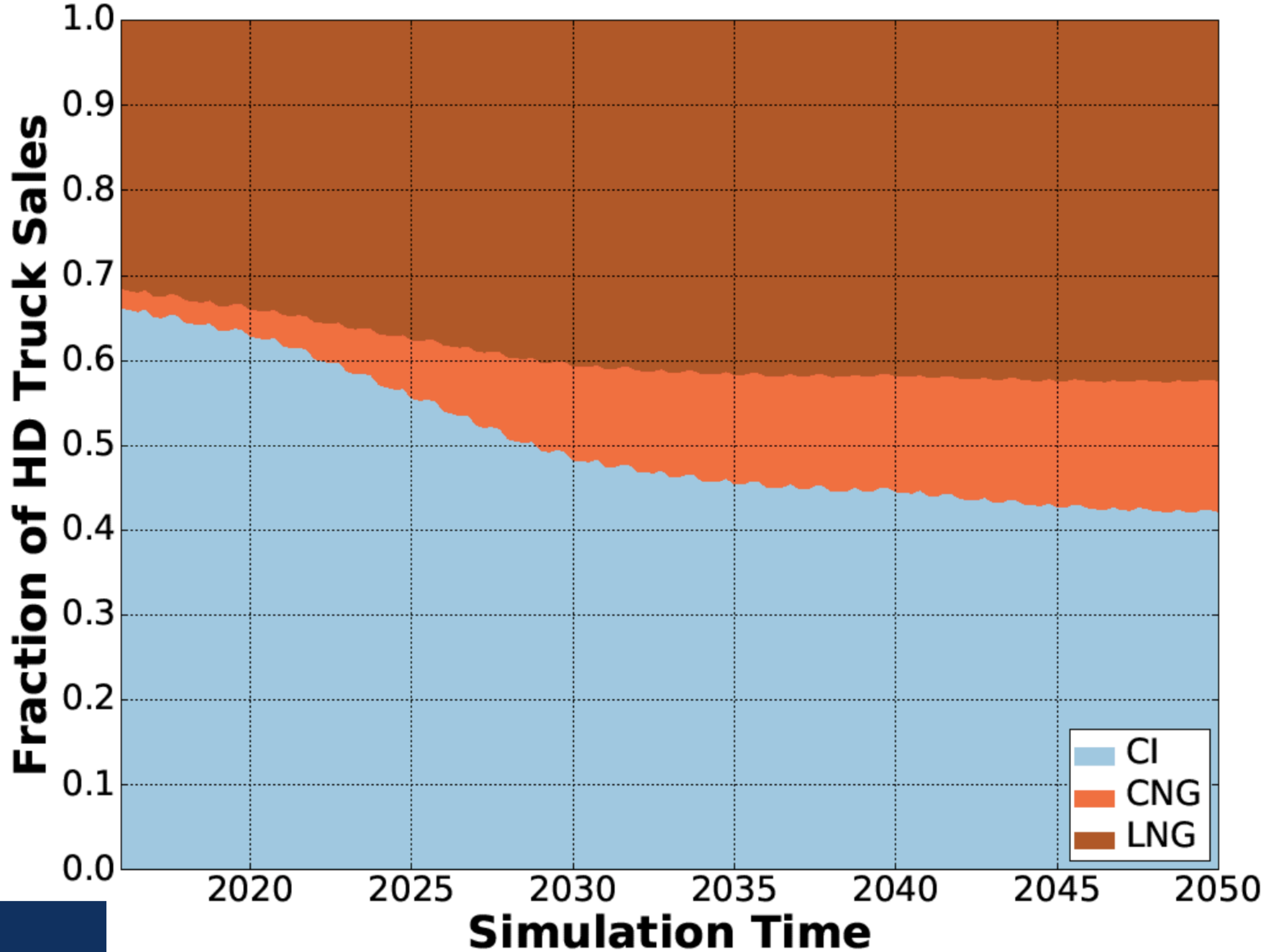

$3.00 NGV Incentive Through 2050

Key Result
Practical NGV incentives have minimal impact on adoption