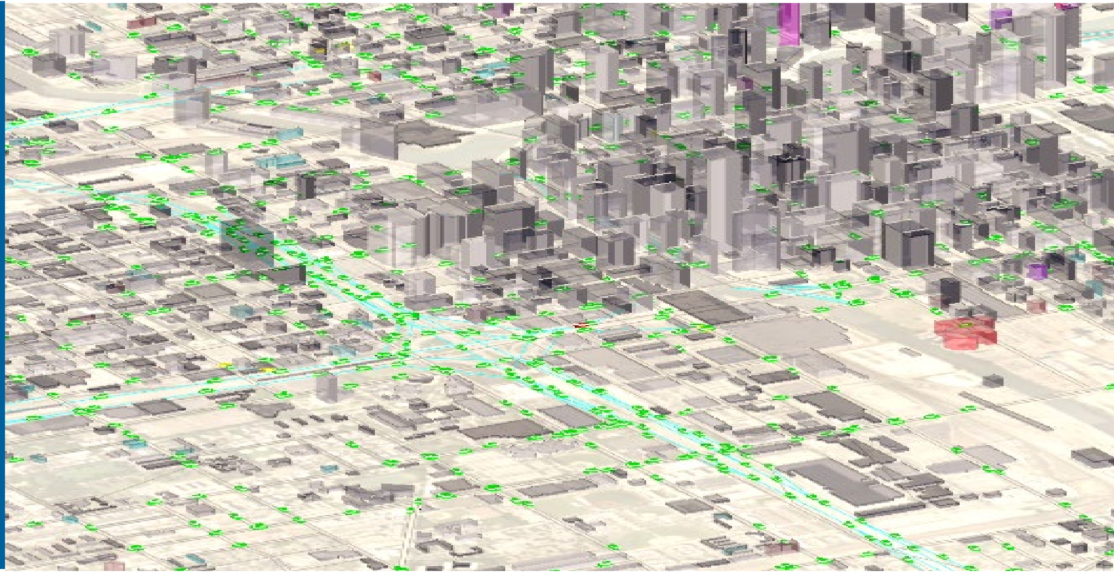
PROJECT ID # VAN035

ASSESSING VEHICLE TECHNOLOGIES BENEFITS IN A TRANSPORTATION ENERGY ECOSYSTEM



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Annual Merit Review 2021, Washington DC

PROJECT OVERVIEW

Timeline	Barriers Addressed
Start date : Sep 2019 End date : Aug 2022	• Risk aversion • Constant advances in technology • Computational models, design, and simulation methodologies *from 2011-2015 VTP MYPP
Budget	**Partners**
Total Project : $900K FY 21 : $300k Percent spent : 60%	• Vehicle Technologies Office • NREL (EVI-Pro) • 21 Century Truck Partnership

RELEVANCE

What are the impacts of VTO technologies across a wide range of real world usage (e.g., different Vehicle Miles Traveled) and modes (e.g., personal, TNC, commercial vehicles) across an entire metropolitan area?

- VTO technology targets benefits have historically been assessed for energy consumption and cost benefit using US regulatory drive cycles
- How do VTO technologies impact vehicle energy consumption, cost, xEV market penetration, number and type of charging stations across an entire metropolitan area for different vehicle classes and timeframes?

OBJECTIVES

1. How does the powertrain technology market share for medium- duty (MD) and heavy-duty (HD) vehicles evolve over time if we minimize cost of driving? (Light duty analysis was conducted last year)
2. How does light-duty Plug-in electric vehicle (PEV) penetration impact the number and usage of charging stations?

MILESTONES

Task completed
In progress
On track

Obj. #1

- 21Q1: Update vehicle stock fleet in POLARIS
- 21Q2: Perform large scale simulations (HPC)
- 21Q3: Quantify VTO Technologies impact on medium (MD) and heavy duty (HD) technology penetration
- 21Q4: Final report on MD/HD truck market penetration

21Q1 21Q2 21Q3 21Q4

Obj. #2

- 21Q1: Incorporate AI models for SOC prediction
- 21Q2: Perform large scale simulations (HPC)
- 21Q3: Quantify impact of PEV penetration on public EVSE deployment
- 21Q4: Final report on impacts of at home charging availability

APPROACH

Obj#1: MD/HD Trucks Powertrain Distribution to Minimize Cost

Individual vehicle routes (OD)

EEMS093

POLARIS

Individual vehicle models VAN023

AUTONOMIE

Four Timeframes (current, short-term, medium-term, long-term)

✖

Five Classes, analyzed in 2 groups (medium and heavy duty)

✖

Five Powertrains (conv, ISG, HEV, PHEV, BEV)

✖

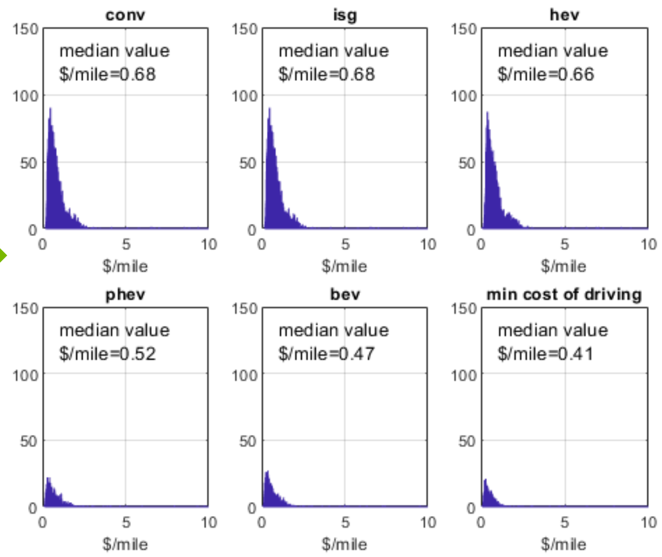
Two Uncertainties (Low and High Technology)

AMBER

EEMS013

Large scale process (HPC)

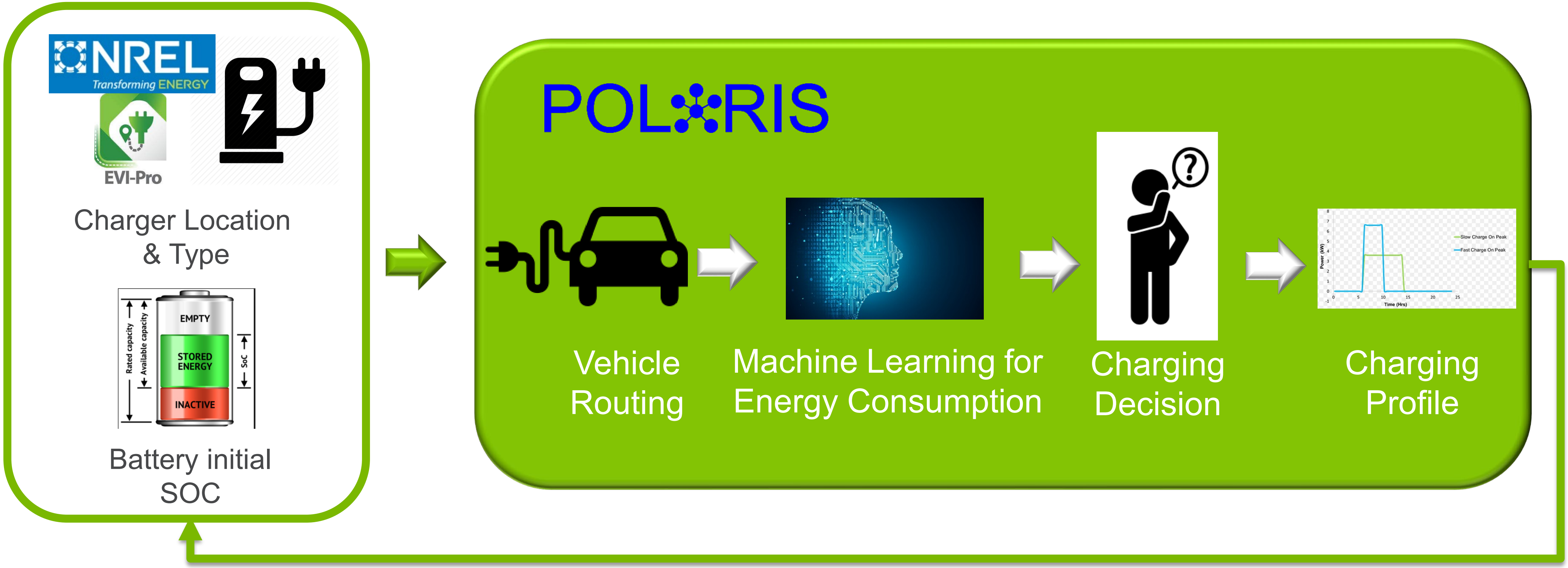
Energy consumption & Cost



Optimum powertrain distribution

APPROACH

Obj#2: EV Penetration and Utilization of Charging Stations



Iterative process required: First POLARIS simulation assumes unconstrained charging -> The outputs are used by EVI-PRO to define charger locations and types -> Second POLARIS simulation considers constrained charging

TECHNICAL ACCOMPLISHMENTS AND PROGRESS

OBJECTIVE #1:

SHARE OF POWERTRAIN TECHNOLOGY TO MINIMIZE COST OF DRIVING FOR MEDIUM AND HEAVY DUTY TRUCKS

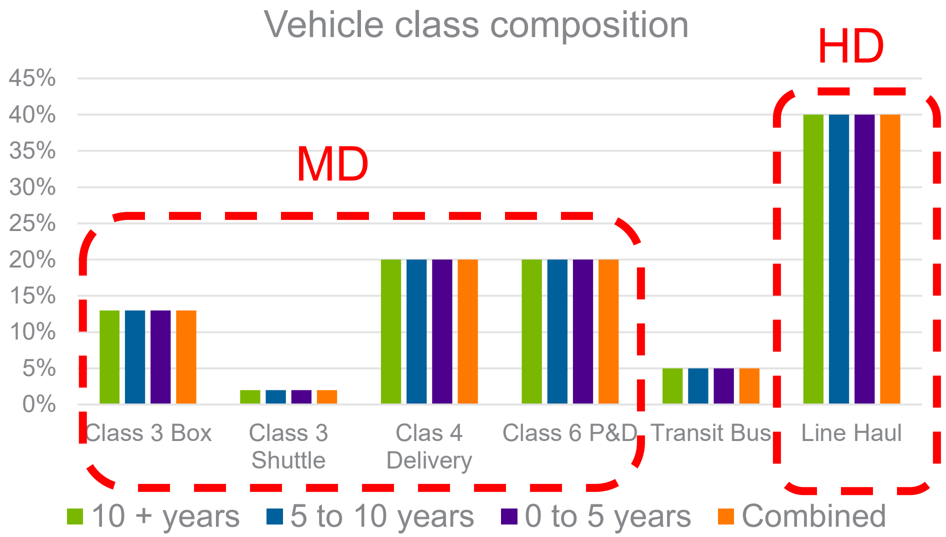
DEVELOPED VEHICLE MODELS TO REPRESENT FLEETS

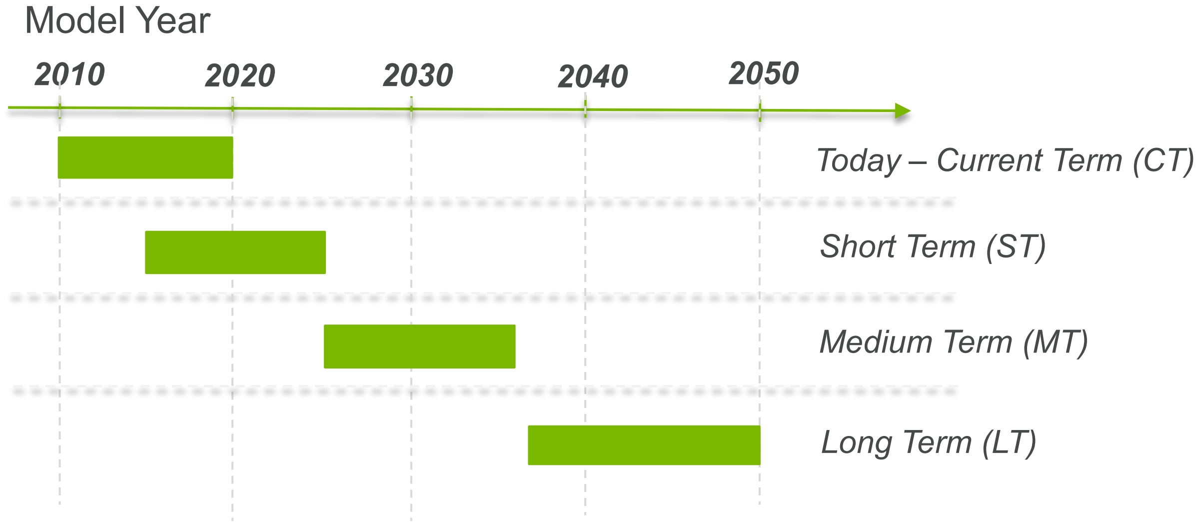
For each timeframe, a fleet is defined by a powertrain, class and vintage distribution

Vehicles in operation by age

	MD & HD	LD
0 to 5 years	29.6%	32.1%
6 to 10 years	30.5%	28.9%
10 + years	39.9%	39.0%

Ref: Transportation Energy Data Book, Edition 39





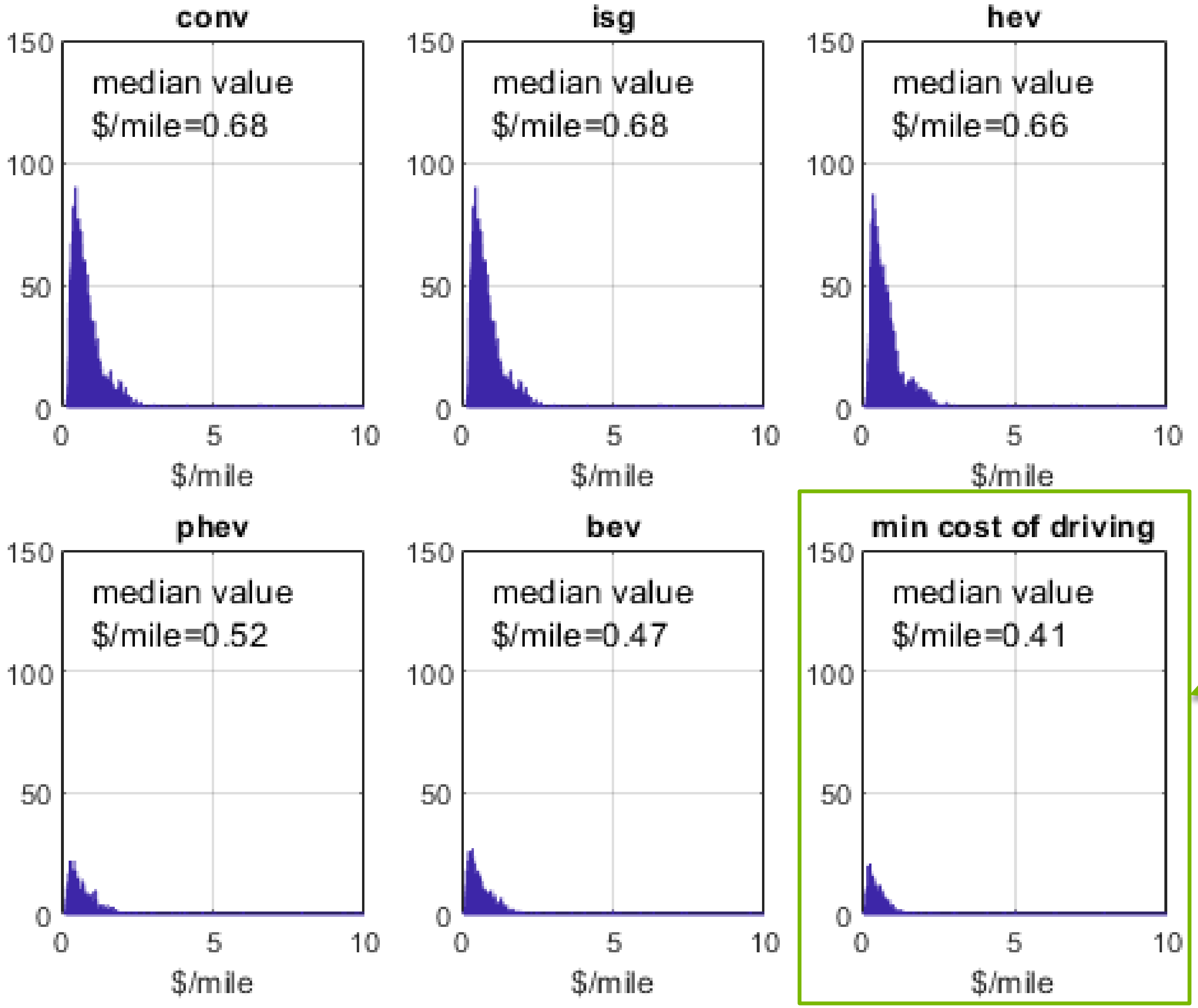
Powertrain composition

CT	ST		MT		LT	
	low	high	low	high	low	high

Low: minimum advancement in technology
High: significant progress in technology adoption

EVERY POWERTRAIN SIMULATED FOR EVERY VEHICLE ON EVERY ROUTE

Example: MD Cost of driving distribution, LT high case, 5012 vehicles



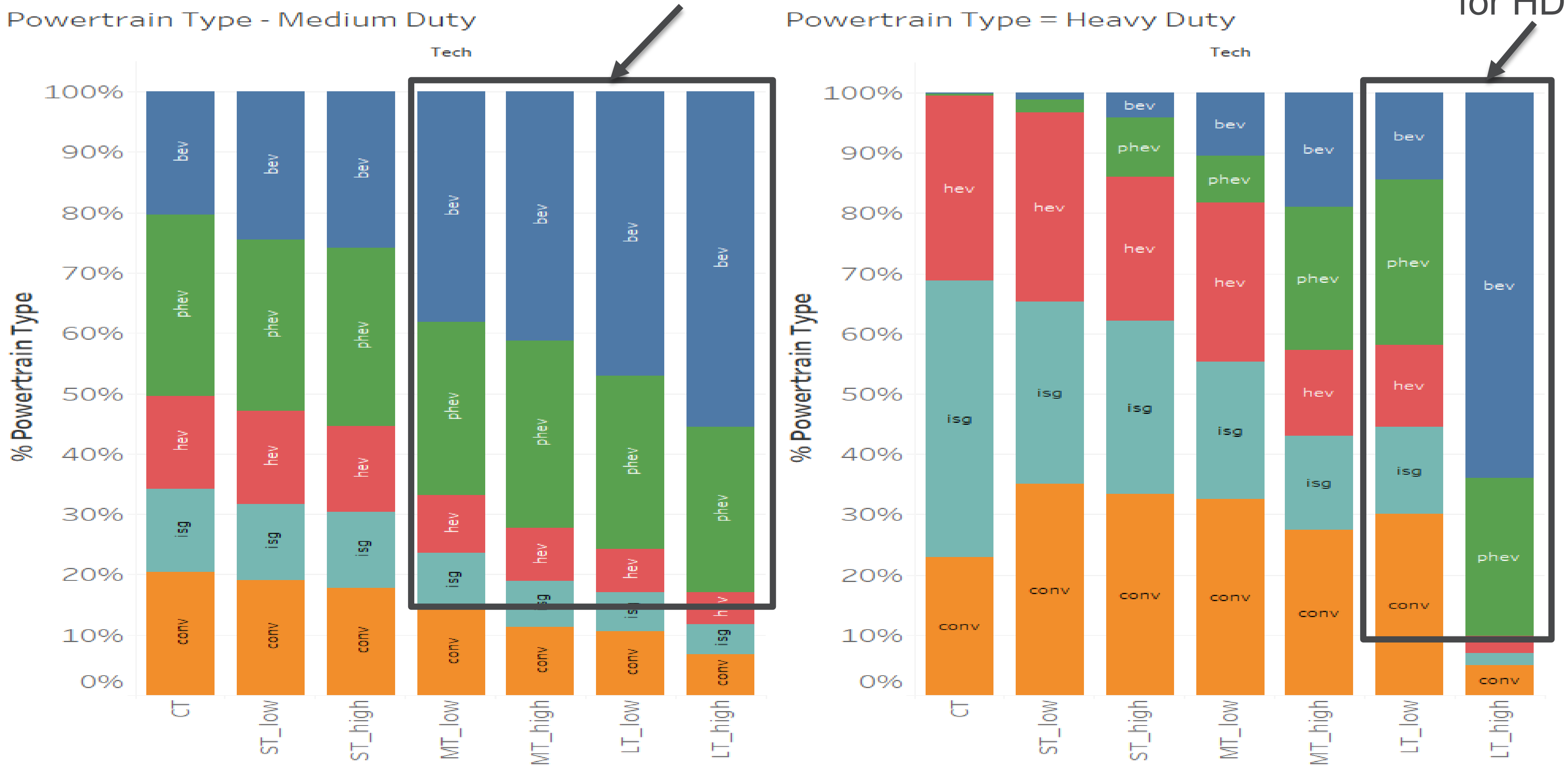
For each vehicle, the cost of driving is calculated using each of the 5 powertrains

The powertrain that provides the lowest cost of driving is selected

SHARE OF ELECTRIFIED POWERTRAINS INCREASES OVER TIME DRIVEN BY LOWER TECHNOLOGY COSTS

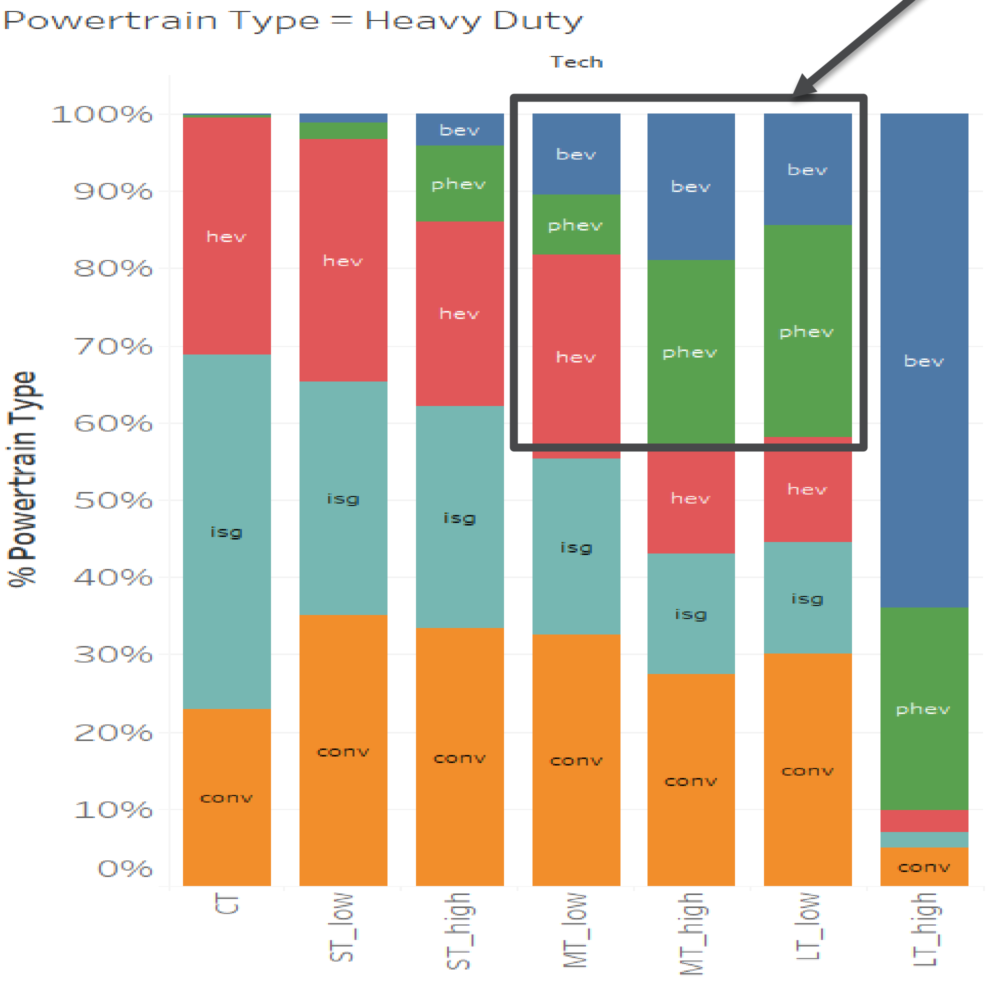
MD achieve higher electrification than HD trucks

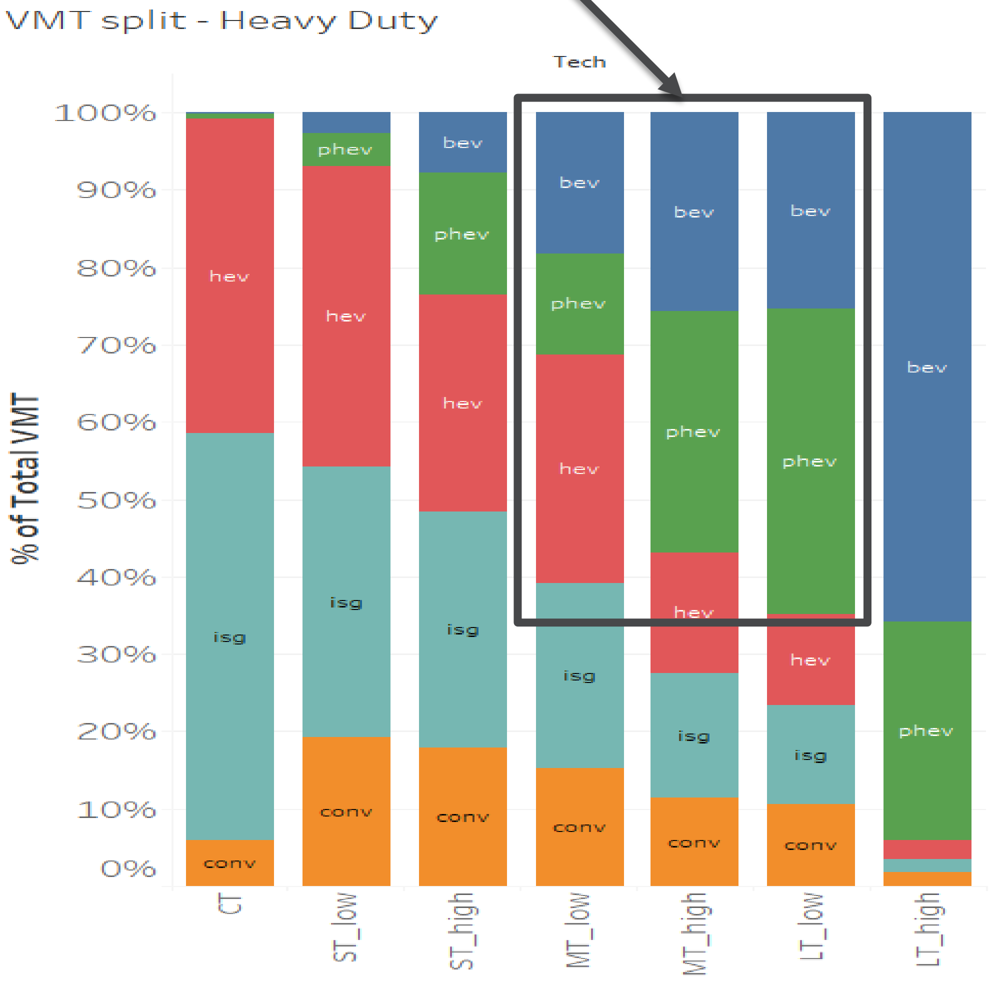
Major PEVs technology improvements are needed for HD Trucks



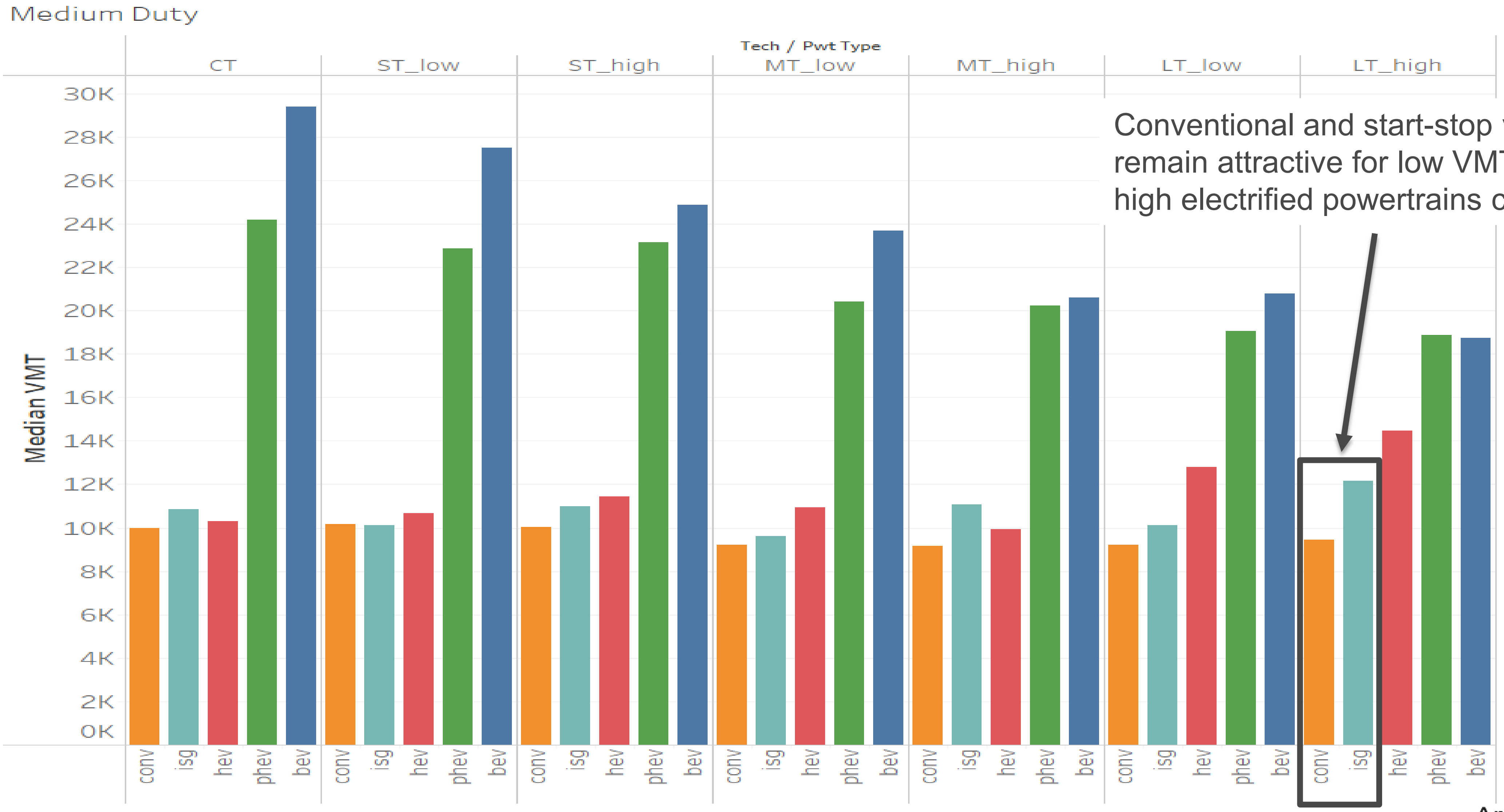
PEV NEED TO BE DRIVEN A LOT TO BE COST COMPETITIVE

Cost competitive PHEVs and
BEVs have higher VMT per vehicle





VMT REQUIRED FOR BEV & PHEV TO BE COMPETITIVE DECREASES OVER TIME



Conventional and start-stop vehicles remain attractive for low VMT due to high electrified powertrains costs

TECHNICAL ACCOMPLISHMENTS AND PROGRESS

OBJECTIVE #2:

EV PENETRATION AND UTILIZATION OF CHARGING STATIONS (LIGHT DUTY ONLY)

SCENARIOS DEVELOPED TO QUANTIFY THE IMPACT OF HOME CHARGING AVAILABILITY

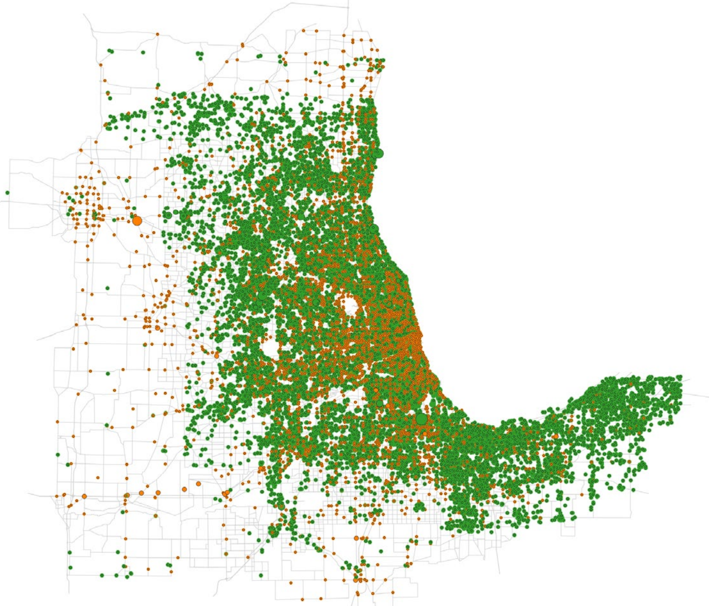
- Four POLARIS scenarios are defined to inform EVI-Pro and EVSE siting
  - Low EV ownership
    - Low home charging availability
    - High home charging availability
  - High EV ownership
    - Low home charging availability
    - High home charging availability
- EV penetration and home charging availability.

Low Ownership - Low Home Chargers			Low Ownership - High Home Chargers		
	Multi-Unit	Single-Unit		Multi-Unit	Single-Unit
EV Ownership	49,300	240,700	EV Ownership	49,300	240,700
Home Charging	2,465	192,560	Home Charging	36,975	240,700
High Ownership - Low Home Chargers			**High Ownership - High Home Chargers**		
	Multi-Unit	Single-Unit		Multi-Unit	Single-Unit
EV Ownership	186,900	703,100	EV Ownership	186,900	703,100
Home Charging	9,345	428,891	Home Charging	93,450	703,100

- In the first step of the analysis (shown next slide), vehicles are assumed to have access to charging whenever they want and wherever they want (“unconstrained”)

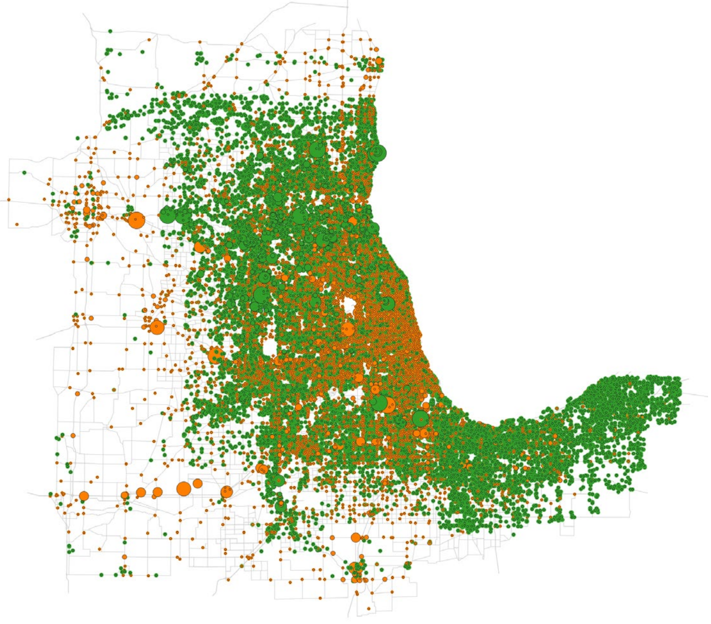
HOME CHARGING MAIN DESIRED CHARGING OPTION

Low EV Ownership – Low Home Chargers – Unconstrained

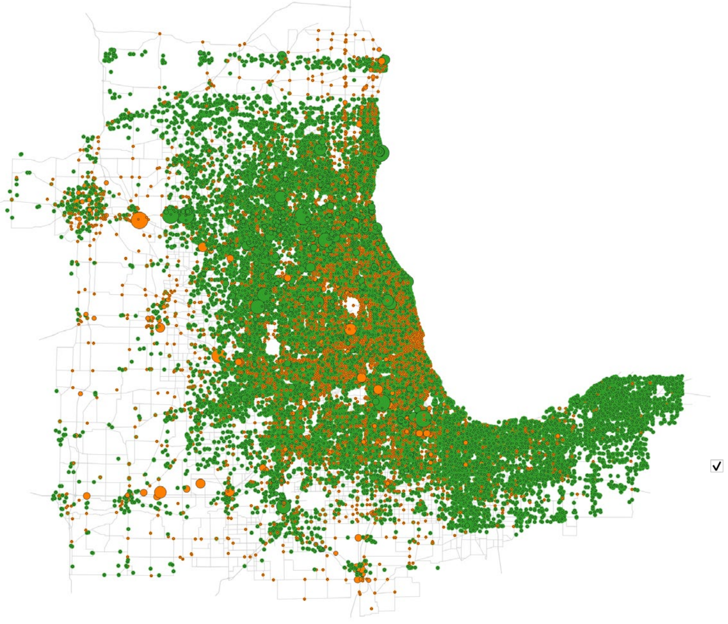


Low EV Ownership – High Home Chargers – Unconstrained

High EV Ownership – Low Home Chargers – Unconstrained

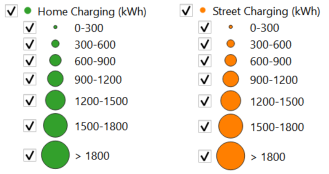


High EV Ownership – High Home Chargers – Unconstrained

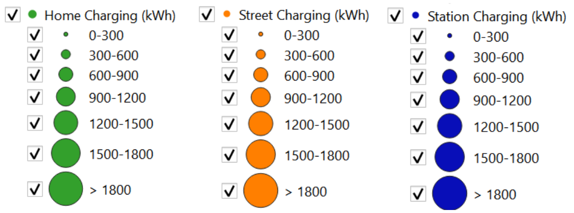


	Home Charging (MWh)	Street Charging (MWh)	Total (MWh)
Low Ownership – Low Home Chargers	783	251	1,034
Low Ownership – High Home Chargers	1,122	190	1,312
High Ownership – Low Home Chargers	1,988	878	2,866
High Ownership – High Home Chargers	3,241	605	3,846

- Higher EV ownership results in more overall charging.
- Higher charger ownership results in more overall charging.
- The increased availability of home charging decreases street charging and increases home charging under a given EV ownership assumption.

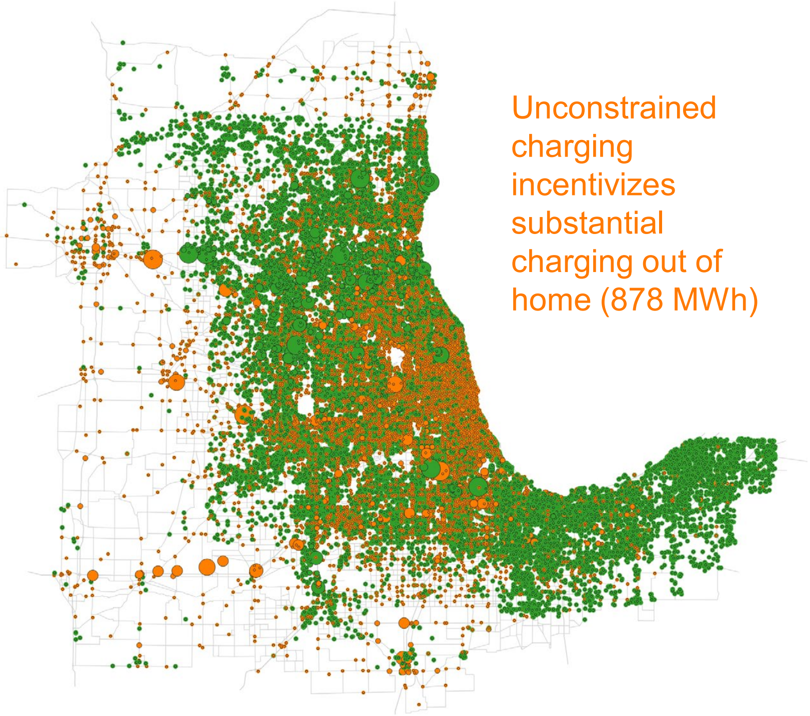


CONSTRAINTS ON PUBLIC CHARGING LEADS TO AN OVERALL REDUCTION IN CHARGING



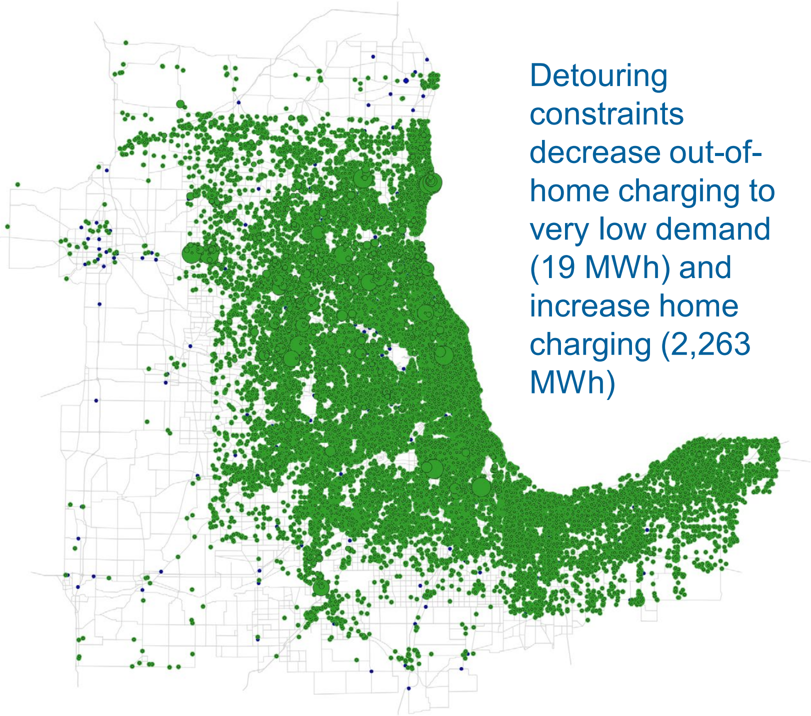
Unconstrained vs Constrained Public Charging

High EV Ownership – Low Home Chargers – Unconstrained – Home Charging & Street Charging



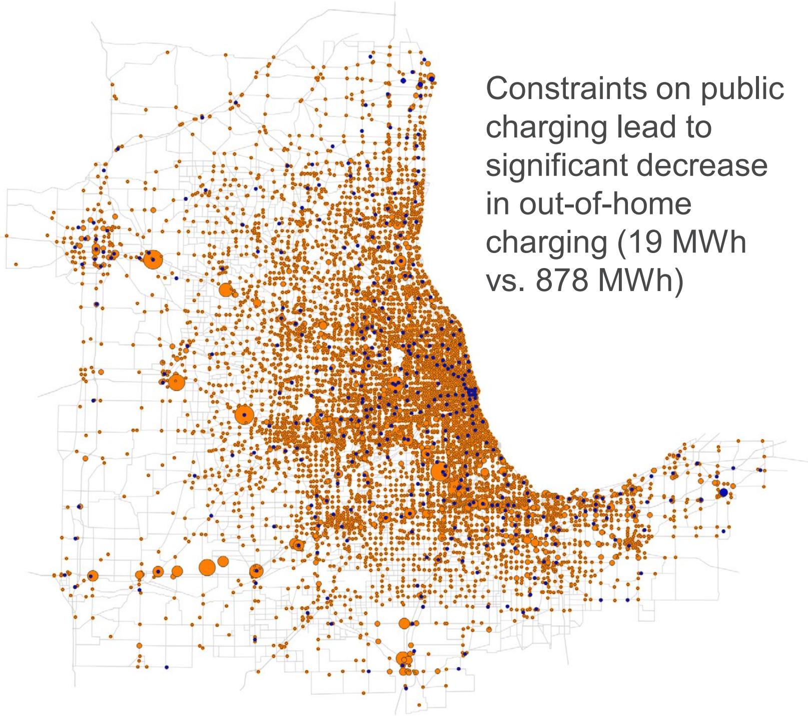
Unconstrained charging incentivizes substantial charging out of home (878 MWh)

High EV Ownership – Low Home Chargers – Constrained – Home Charging & Station Charging



Detouring constraints decrease out-of-home charging to very low demand (19 MWh) and increase home charging (2,263 MWh)

Out of Home Charging across 2 Scenarios – Unconstrained vs Constrained (Street vs Station)



Constraints on public charging lead to significant decrease in out-of-home charging (19 MWh vs. 878 MWh)

	Home Charging (MWh)	Street/Station Charging (MWh)	Total (MWh)
High Ownership – Low Home Chargers – Unconstrained	1,988	878	2,866
High Ownership – Low Home Chargers – Constrained	2,263	19	2,281

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REMAINING CHALLENGES AND BARRIERS

- Very large number of simulations need to be performed
  - For each POLARIS scenario, all the routes have to be simulated for each powertrain configuration
  - Need high performance computing and automated process (both to perform and analyze the simulations)
- No market penetration tool currently includes all the vehicle classes (light to heavy duty), powertrain and automation levels

  $\Rightarrow$ Comparison is difficult

RESPONSES TO PREVIOUS YEAR REVIEWERS' COMMENTS

The project was not previously reviewed

PROPOSED FUTURE RESEARCH

- Share of powertrain technology based on cost of driving for MD/HD vehicles
  - Implement vehicle routing problem (VRP) algorithms for freight transport in POLARIS
    - This will allow to get VMT information directly from POLARIS
  - Define the appropriate portion of POLARIS routes to simulate to get a representative assessment of energy consumption
  - Perform analysis for individual vehicle classes/applications
  - Compare results with market penetration tools predictions

- EV penetration and the utilization of charging stations
  - Implement machine learning models for energy consumption of BEV for all classes
  - Implement station queuing
  - Implement additional behavioral models
    - Which station to go based on previous knowledge on station crowdedness
    - If a slow charger becomes available, does the traveler start charging or keep waiting for a fast charger to become available?

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

COOPERATION AND COLLABORATION

Inputs

U.S. DEPARTMENT OF ENERGY SMARTMOBILITY Systems and Modeling for Accelerated Research in Transportation

21st CENTURY TRUCK PARTNERSHIP[SM]

USDRIVE DRIVING RESEARCH AND INNOVATION FOR VEHICLE EFFICIENCY AND ENERGY SUSTAINABILITY

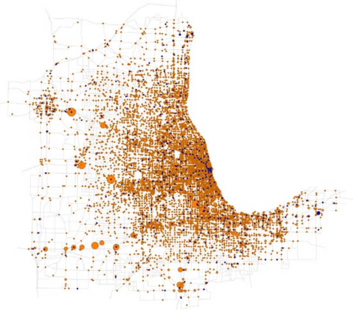
National Labs.

…

Analysis & Reports

Optimum MD/HD powertrain distribution

Impact of at-home charging availability



Stakeholders

- VTO and HFTO Benefits
- SMART Mobility Consortium
- 21CTP Freight Operational Efficiency Tech Team
- Market penetration tools (MA3T, ADOPT)
- U.S DOT
- U.S. EPA
- Research organizations (IEA, AVERE…)
- …

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SUMMARY

Using a transportation network provides a more granular and complete assessment of powertrain technologies (compared to regulatory drive cycles) as well as the interactions with EVSE

- Based on the cost of driving for MD & HD, the share of electrified powertrains increases over time but, in all cases, a powertrain mix provides the lowest cost.
- To offset their higher vehicle cost, PHEV and BEV should be used on longer routes (high VMT)
- Based on this analysis, the share of highly electrified powertrain could be significantly higher than what was assumed in previous studies (EEMS093).
- Privately owned EV are used more when home charging is available
- Even in a scenario of high EV ownership and low availability of home charging, most of the charging occurs at home

BACKUP SLIDES

TCO CALCULATION ASSUMPTIONS

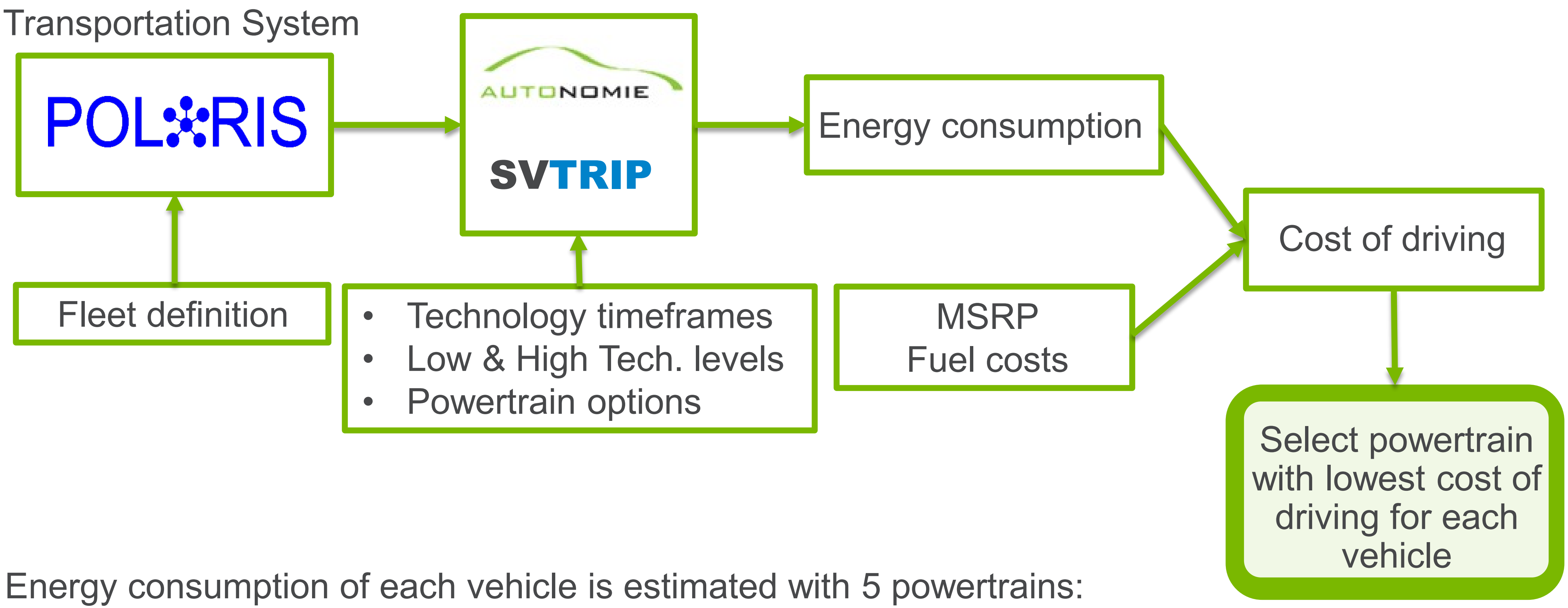
» **Cost of driving ($/mile) = (MSRP – residual value + energy cost) / distance**

- MSRP = Manufacturing cost * 1.2 (Retail Price Equivalent)
- Residual value assumes 15% depreciation over the service time
- Energy cost is the discounted cost of energy over the service time
- Distance is annual VMT multiplied by service time
- Service time is set to 5 years for HD and 15 years for MD
- Discount rate of 4%
- Cost for electricity, gasoline and diesel cost are derived from the 2020 IEA Energy Outlook
- Other costs such as insurance and maintenance are not included

APPROACH

System level analysis using multiple tools integrated into a workflow

This workflow was developed in SMART 1.0

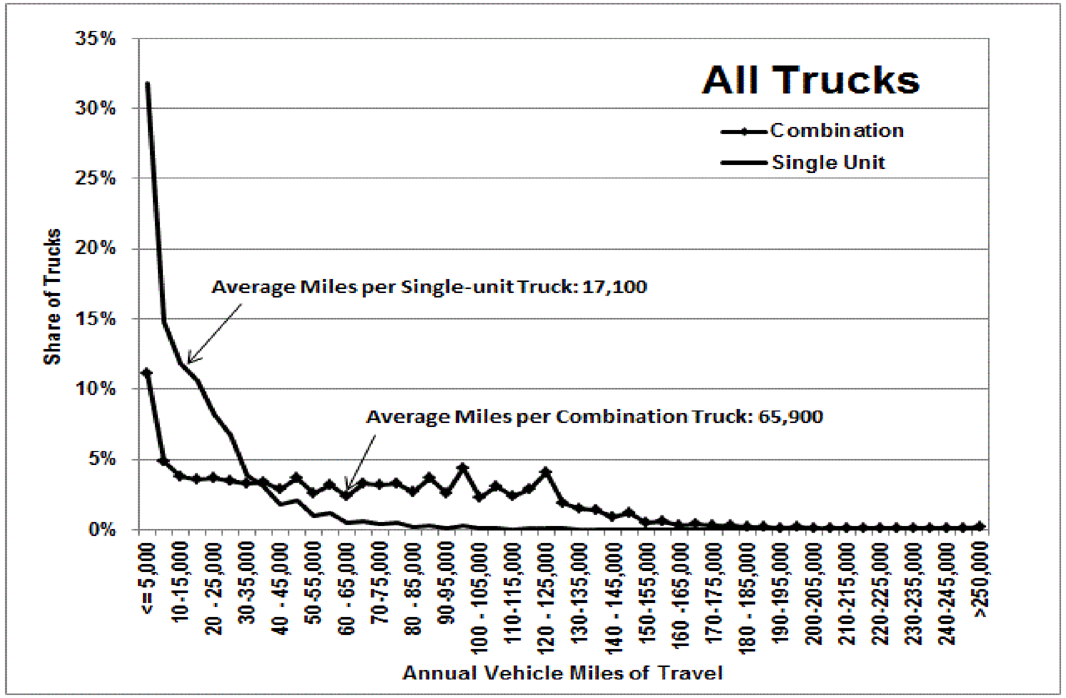


Energy consumption of each vehicle is estimated with 5 powertrains:

Conventional, ISG, HEV, PHEV, BEV

VEHICLE MILES TRAVELED (VMT)

- Single-unit truck data → MD
- Combination truck data → HD



Ref: Transportation Energy Data Book, Edition 39

TRIP CHARACTERISTICS

A Chicago baseline scenario from Polaris is used for this analysis

- Characteristics of the trip database:
  - MD
    - 5072 trips
    - Average trip distance = 6.2 miles
    - Average trip speed = 35 mph
  - HD
    - 5012 trips
    - Average trip distance = 37 miles
    - Average trip speed = 46 mph

- Powertrain choice
  - Conventional
  - ISG
  - HEV
  - PHEV
    - » 75 miles for MD
    - » 250 miles for HD
  - EV
    - » 150 miles for MD
    - » 500 miles for HD

Charging Behavior Decision