Project ID# EEMS0058

U.S. DEPARTMENT OF ENERGY

SMARTMOBILITY

Systems and Modeling for Accelerated Research in Transportation

Systems and Modeling for Accelerated Research in Transportation (SMART) Mobility Consortium Tools and Process Development

Aymeric Rousseau
Argonne National Laboratory
2019 Vehicle Technologies Office Annual Merit Review
June 12, 2019

Argonne NATIONAL LABORATORY | INL Idaho National Laboratory | BERKELEY LAB | OAK RIDGE National Laboratory | NREL NATIONAL RENEWABLE ENERGY LABORATORY

PROJECT OVERVIEW

Timeline	Barriers
• Project start date : Oct. 2018 • Project end date : Sep. 2019 • Percent complete : 60%	• High uncertainty in technology deployment, functionality, usage, impact at system level • Computational models, design and simulation methodologies • Integration of many model frameworks: land use, demand, flow, vehicles, grid, economy
Budget	**Partners**
• FY19 Funding Received : $1,000,000	• Argonne (Lead) • LBNL, NREL, ORNL, INL, LLNL • Universities (UCI, GMU, UIC, Texas A&M, Taxas At Austin, UNSW, Washington)

PROJECT RELEVANCE

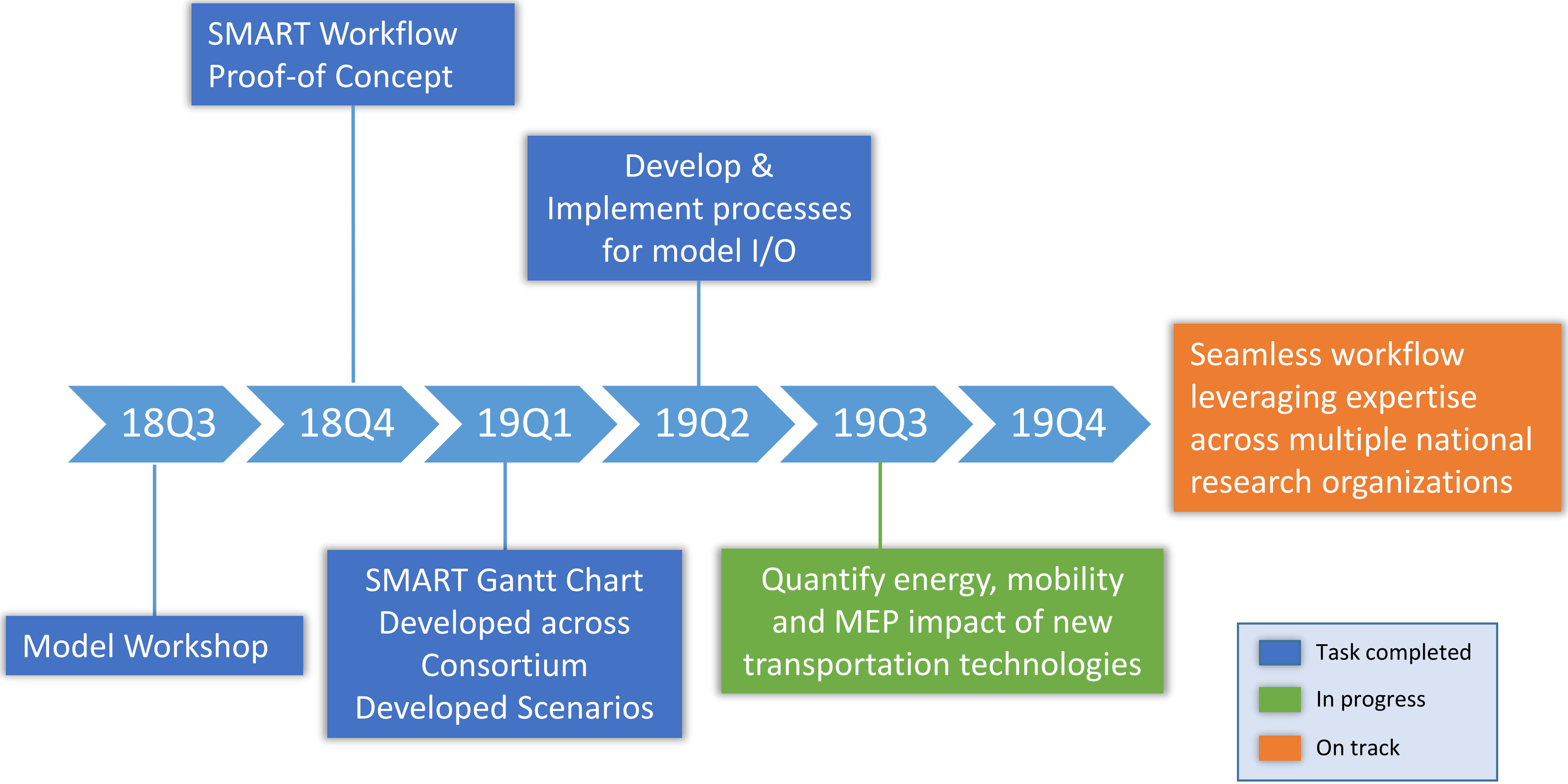
System level workflow is required to answer complex questions and provide actionable information

- What is the impact of vehicle **fleet sharing, multi-modal travel, personally owned fully automated vehicles** on mobility, energy, Vehicle Miles Travelled (VMT), Mobility Energy Productivity (MEP)…?
- How is **intra-city freight** impacted by disruptive technologies, such as e-commerce, electrification, in-route passenger delivery systems?
- What is the potential to increase efficiency through **advanced vehicle control** enabled by connectivity and automation?

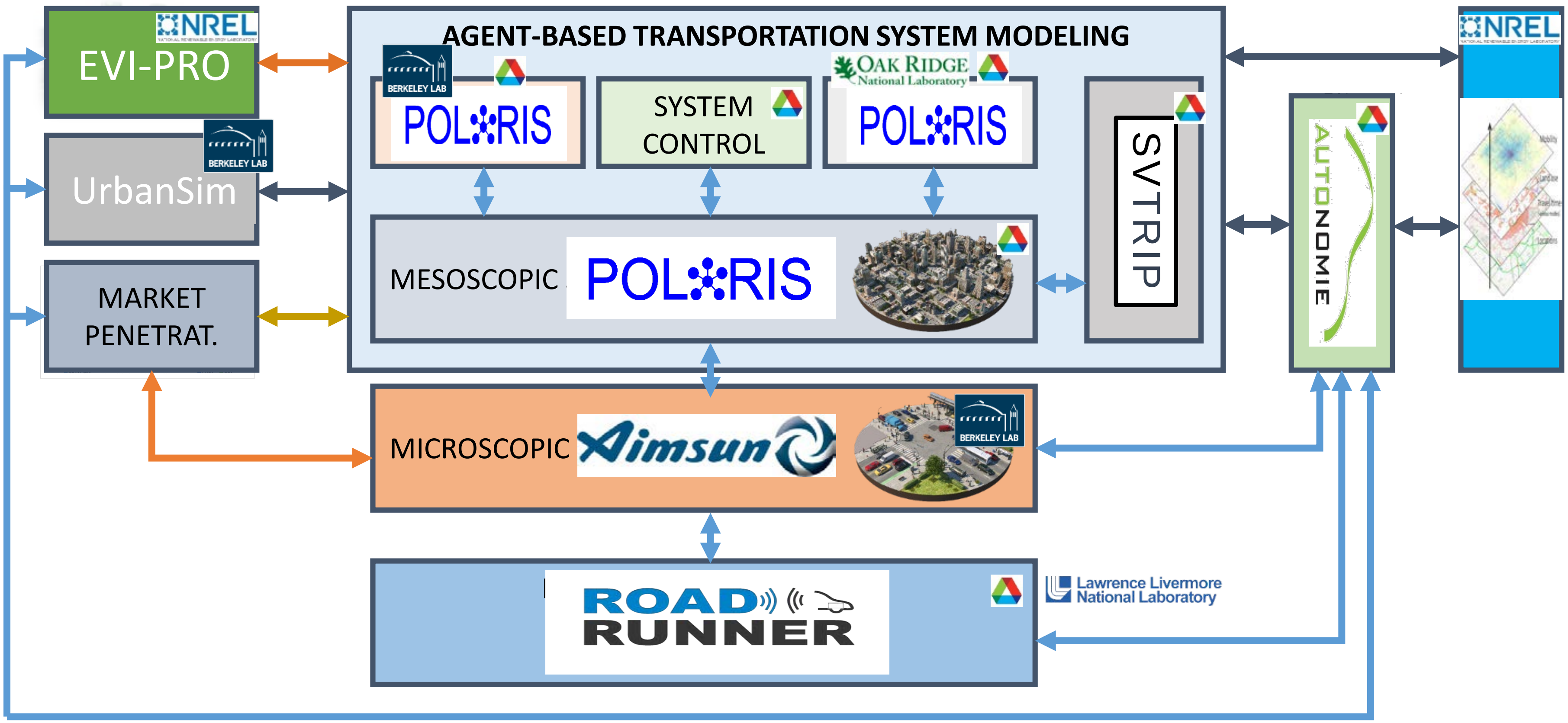
Workflow needs to be deployed to engage with stakeholders and other researchers

- Computationally efficient (<12h)
- Easy to use
- Deployable process
- Model agnostic

MILESTONES

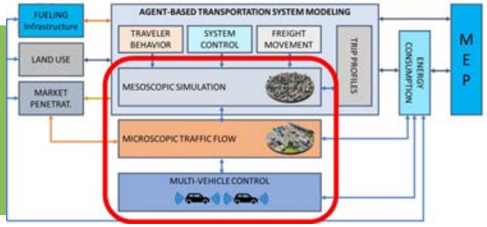

SMART Workflow Proof-of Concept
Develop & Implement processes for model I/O
Seamless workflow leveraging expertise across multiple national research organizations
18Q3
18Q4
19Q1
19Q2
19Q3
19Q4
Model Workshop
SMART Gantt Chart Developed across Consortium Developed Scenarios
Quantify energy, mobility and MEP impact of new transportation technologies
Task completed
In progress
On track

APPROACH - SMART WORKFLOW
A COMPREHENSIVE APPROACH TO ANSWER COMPLEX QUESTIONS



TECHNICAL ACCOMPLISHMENTS AND PROGRESS
TOOL LINKAGES

LEARNING FROM DETAILED MODELS TO SCALE TO LARGER ONES



Current

Future

EEMS031

Microsimulation

Aimsun

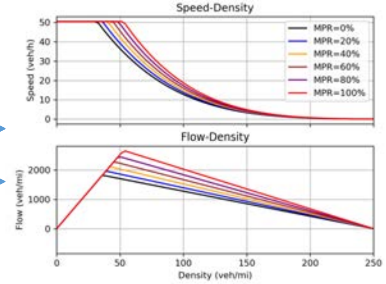
BERKELEY LAB

Freeway corridor with different level market penetration of CAVs

Urban corridor

EEMS075

Fundamental Diagram POLARIS Input



Parameters

Mesosimulation

Driver model, control

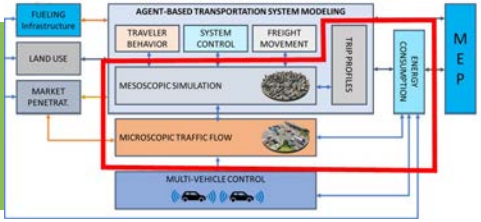
ROAD RUNNER

Argonne NATIONAL LABORATORY

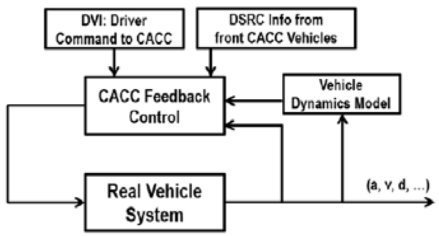
EEMS016

Model & calibration improvement

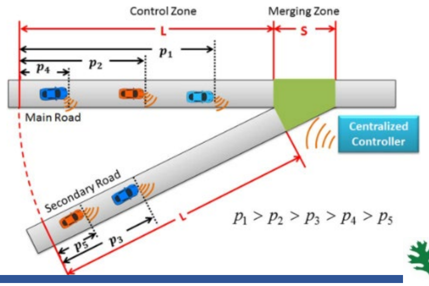
AUTONOMIE REUSED ACROSS CONSORTIUM



ACC / CACC Control



CAVs Coordination



Travel Behavior

Microscopic & Mesoscopic Simulations -> Autonomie for Energy
=> Provides consistent and comparable results

Individual vehicles speed

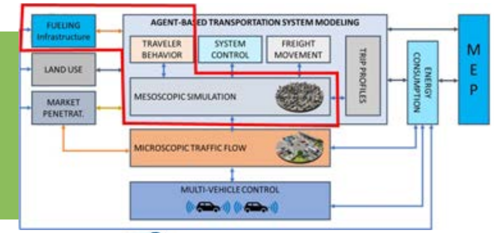
EEMS013, VAN023

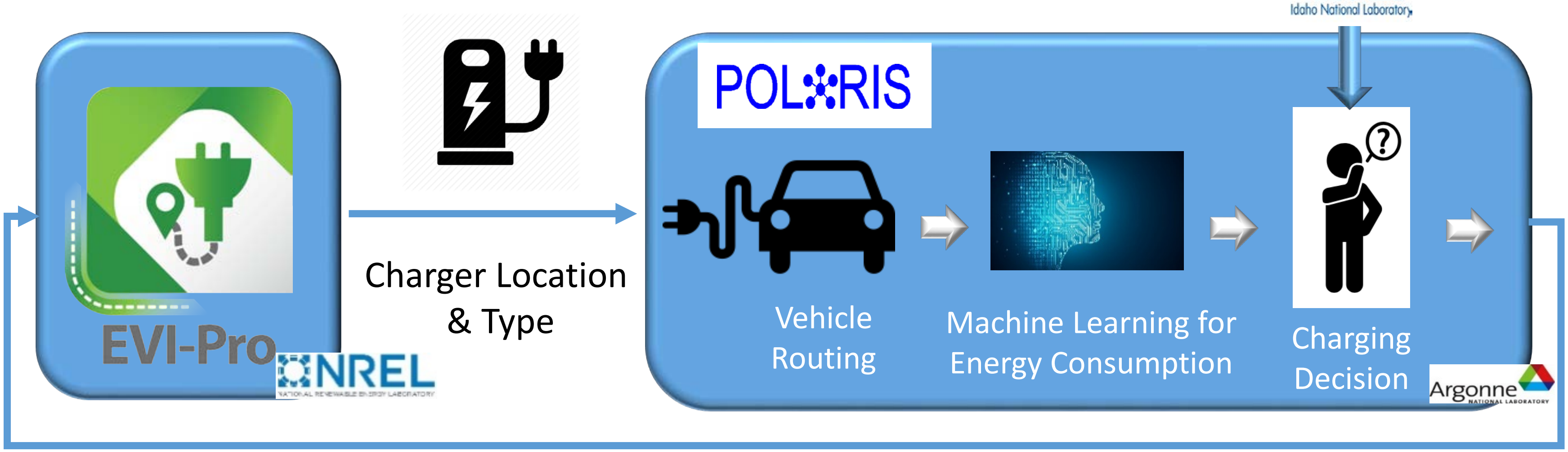
AUTONOMIE
Vehicle Models

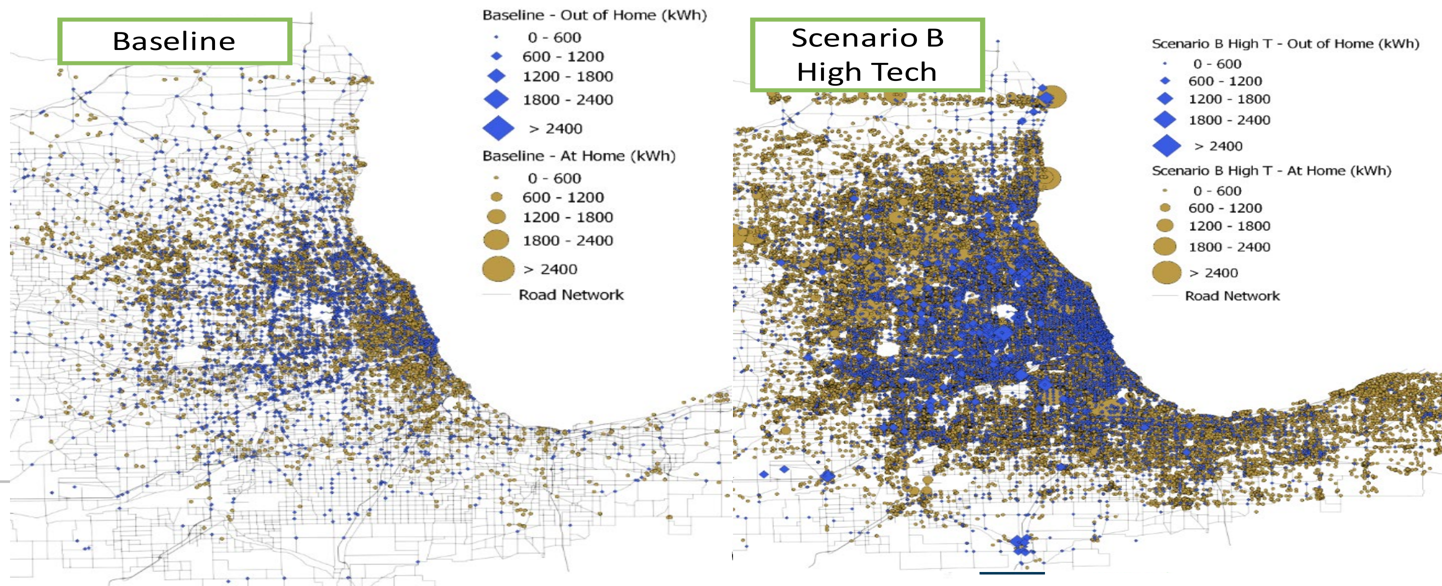
Vehicle energy consumption, cost…

EEMS017, EEMS020, EEMS031, EEMS060, EEMS077, EEMS078

PEV CHARGING LOCATION AND BEHAVIOR

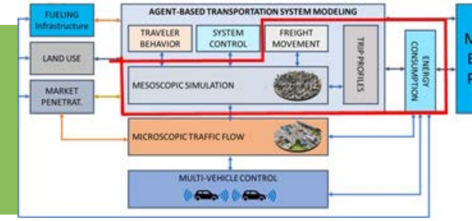




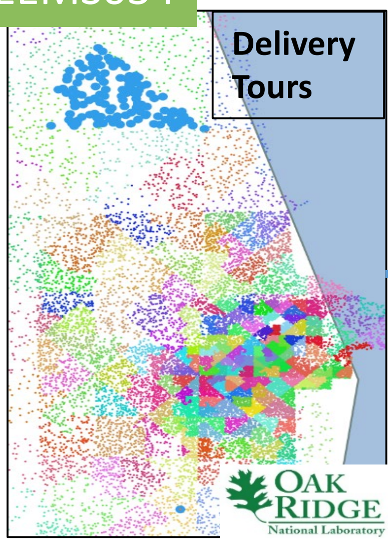


EEMS068

IMPROVED SCENARIOS – FREIGHT EXAMPLE

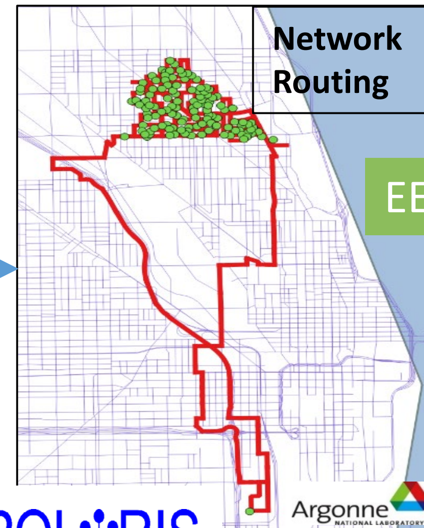


EEMS034

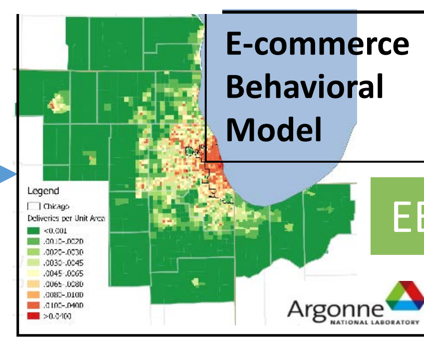


Base year:
Traffic Analysis Zone -Level: Total Parcel Deliveries
Stop-Level: Random Delivery Locations
Medium Duty Delivery Tours

POLARIS



EEMS060



EEMS078

SVTRIP

AUTONOMIE

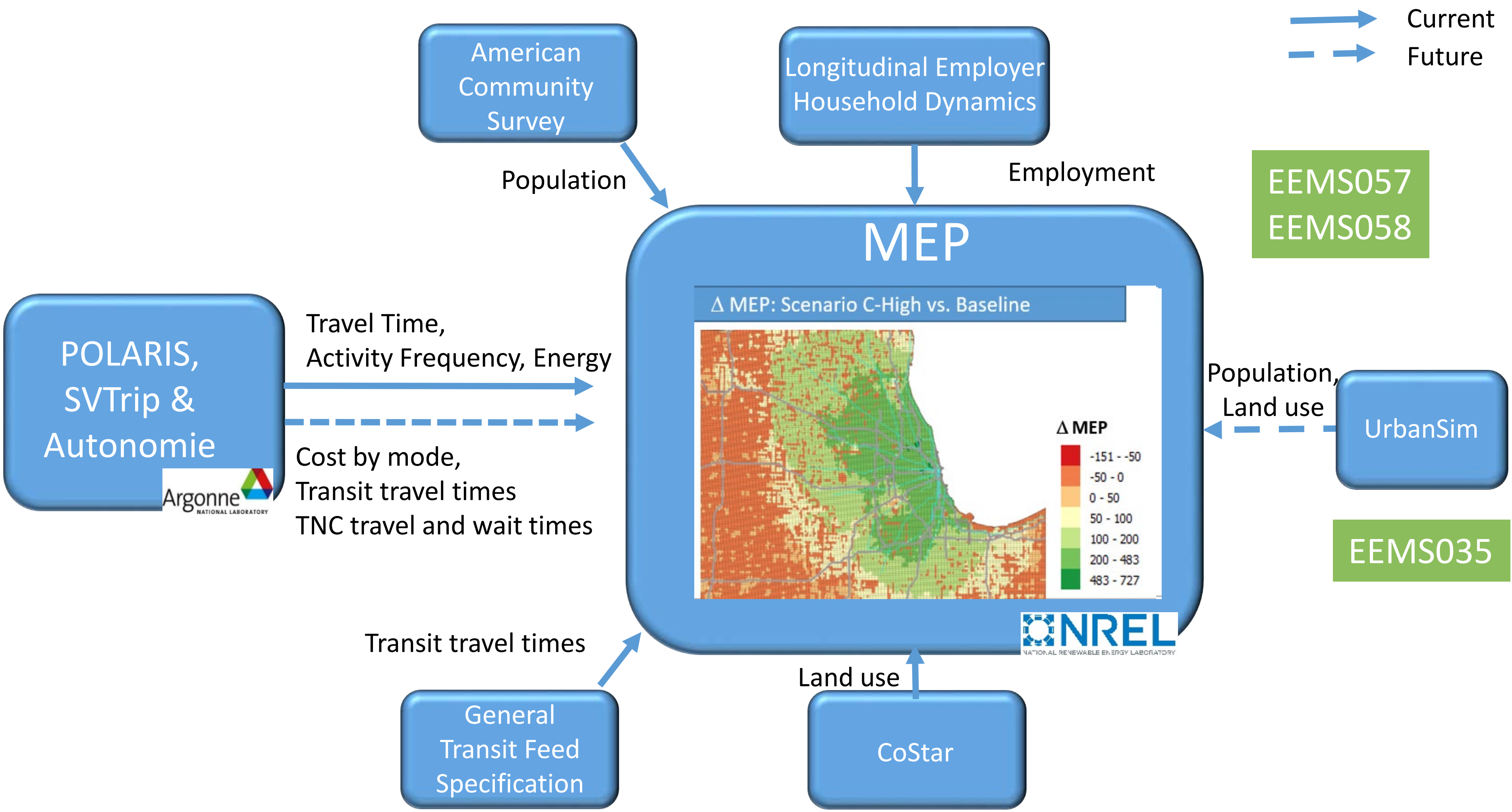
EEMS17, EEMS60, EEMS77

WholeTraveler

Survey Data

EEMS023

AGGREGATING ALL RESULTS TO CALCULATE MEP

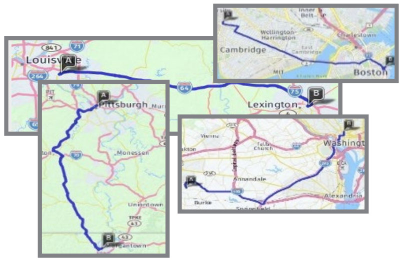


TECHNICAL ACCOMPLISHMENTS AND PROGRESS
PROCESS DEVELOPMENT & DEPLOYMENT

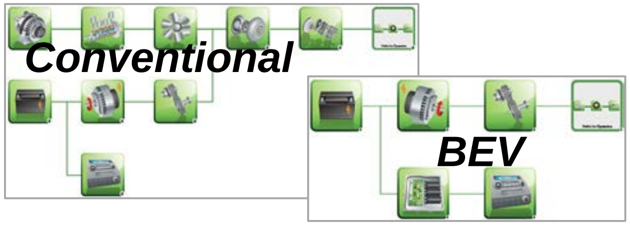
AUTOMATED THE SIMULATION OF LARGE NUMBER OF SCENARIOS IN ROADRUNNER

1. Define Scenario and Select Powertrain

Routes:
Real-world routes from HERE maps

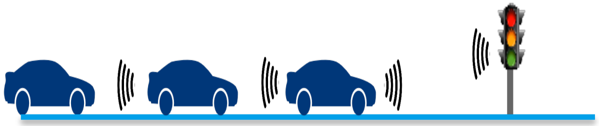


Vehicles: Powertrain models from Autonomie



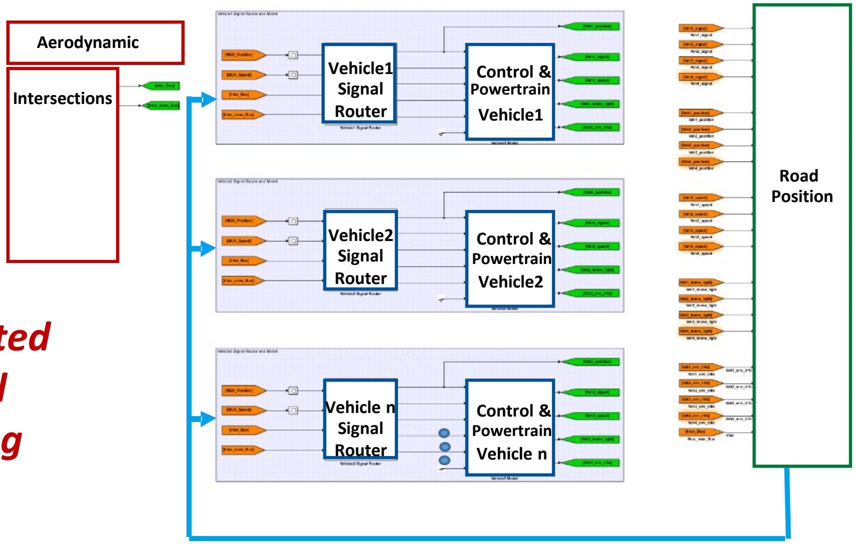
Control: Human, CAV w/ eco-driving, etc.

Number of vehicles, Connectivity level



Automated Model Building

2. Simulate Scenario



HIGH PERFORMANCE COMPUTING (HPC) DEPLOYMENT LEVERAGES DOE R&D & ENABLES CALIBRATION

- HPC Computational/Optimization framework builds on Argonne's Swift/T and EMEWS[1] platforms to manage and run tens of thousands of simulations

POLARIS

Linux HPC
Distributed & Parallel HPC

SVTRIP

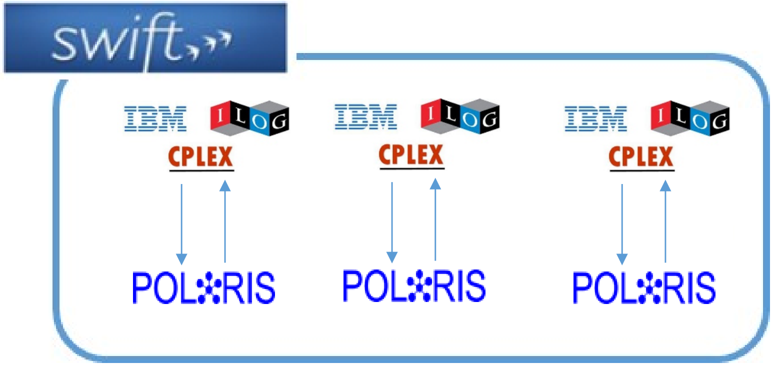
Windows HPC
Parallel computing

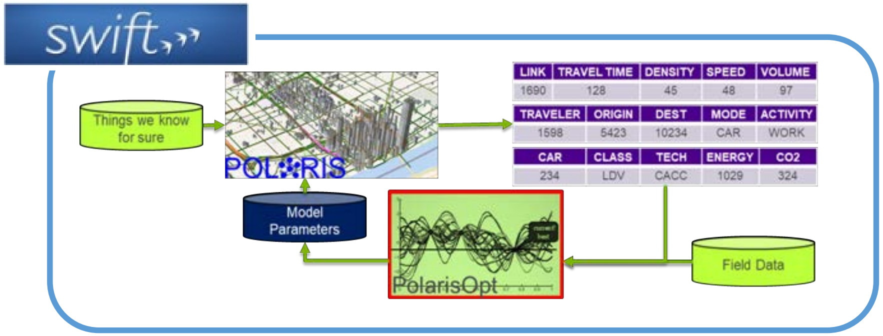
AUTONOMIE

Windows HPC
Parallel computing

Optimization
(e.g. platooning, shared AVs…)

Calibration
(Critical for deployment & adoption)

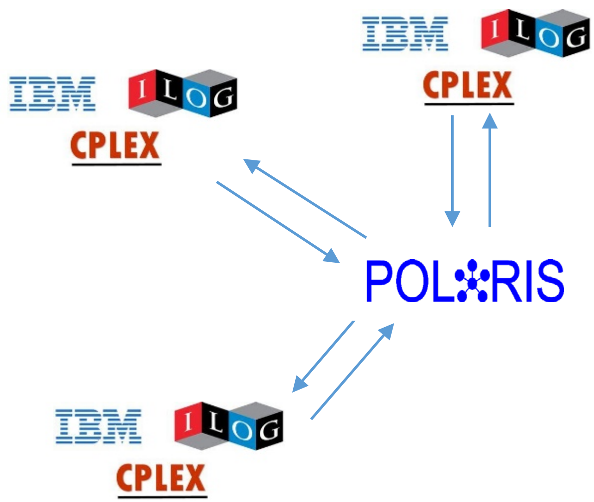




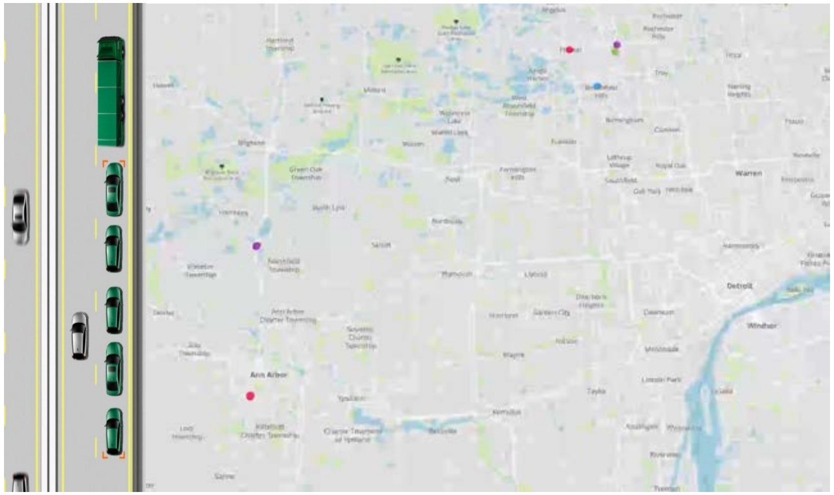
(1) Extreme-scale Model Explora on With Swift

HPC ENABLES OPTIMIZATION & CONTROL

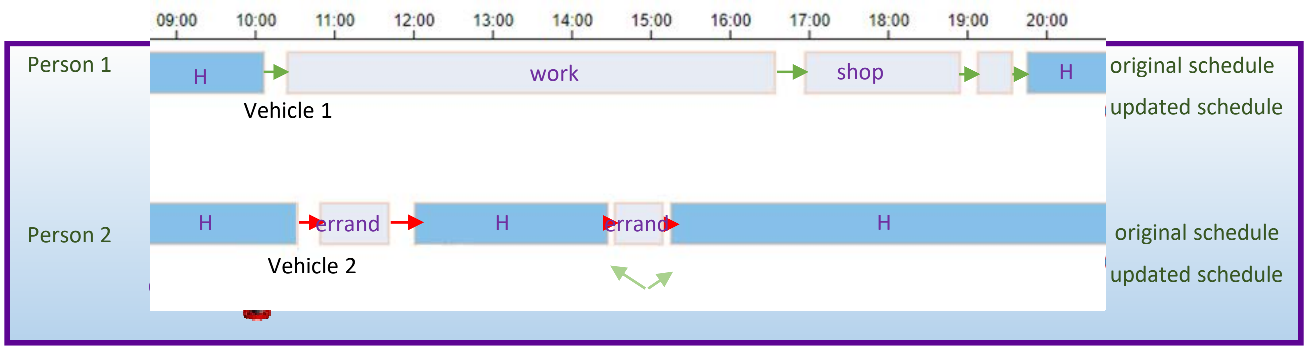
Implemented processes to efficiently link to external optimization tools



Example: Platoon Formation Decision



Example: Personally Owned AVs



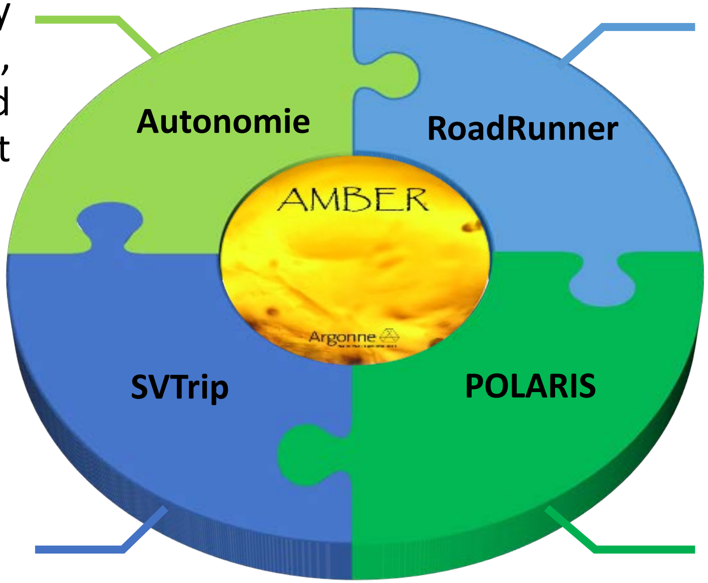
Critical for "All About Me" scenario

NEW WORKFLOWS DEVELOPED IN AMBER FOR DEPLOYMENT/ADOPTION

AMBER is a new workflow manager developed over the past 5 years

Accurate Vehicle Energy Consumption, Performance and Cost

Multi-Vehicle Simulation Environment for Control



Stochastic Vehicle Trip Profile Prediction from Geographic Information System (GIS)

Agent based transportation system simulation

Deployment critical to support Metropolitan Planning Organizations, Cities and organizations on Future Strategic Plans

=> Identify solutions minimizing infrastructure investments

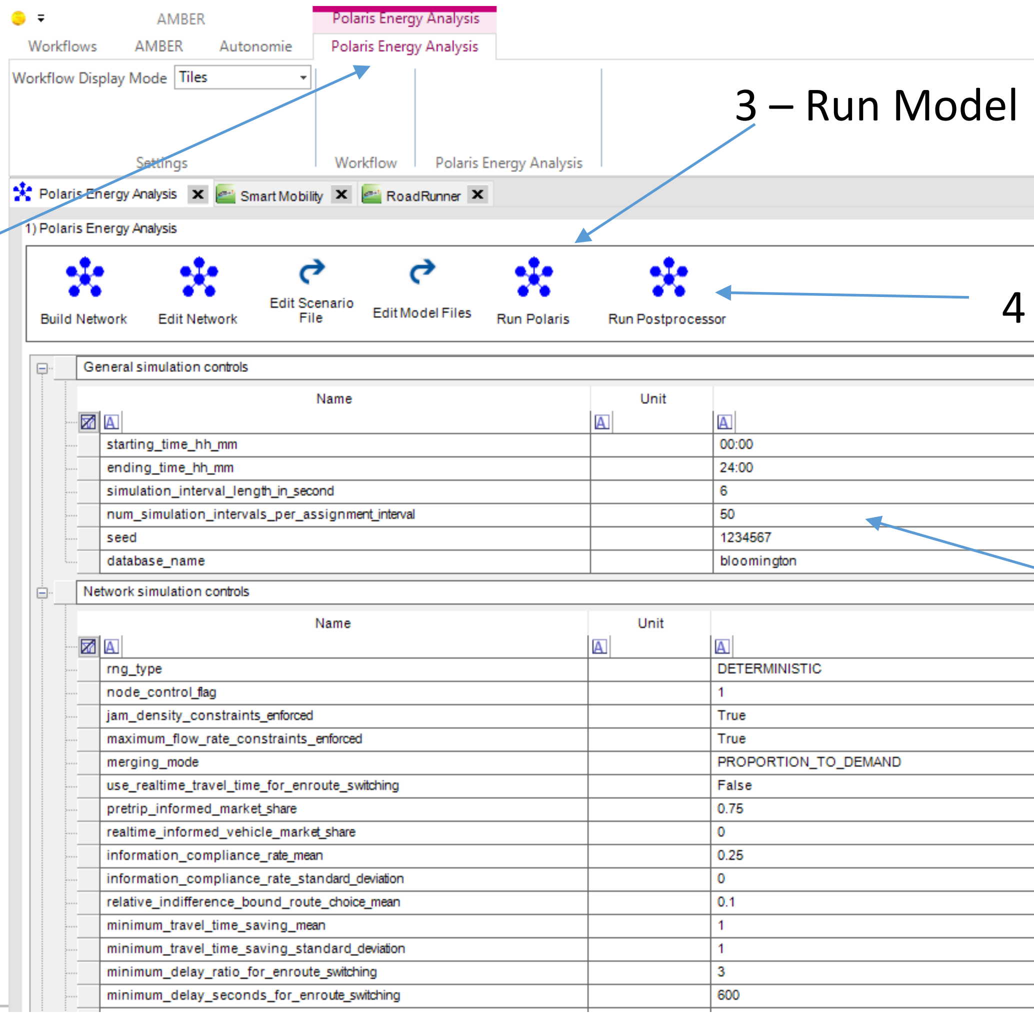
NEW AMBER WORKFLOW - POLARIS EXAMPLE

1 – Load Existing POLARIS Model

2 – Select Parameters

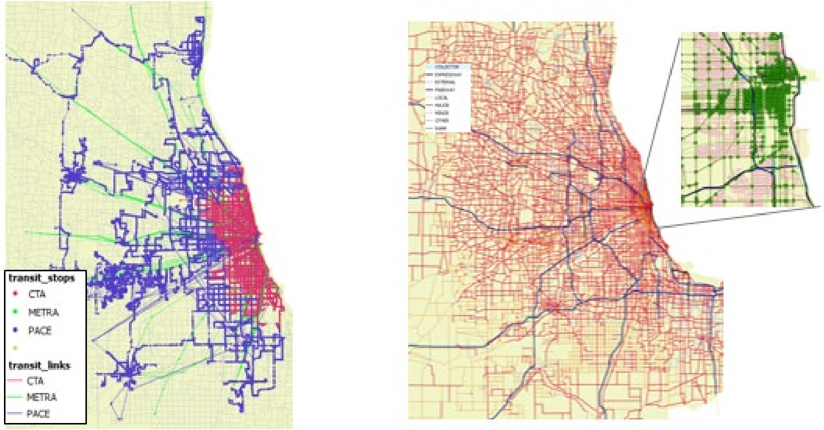
3 – Run Model

4 – Analyze Results



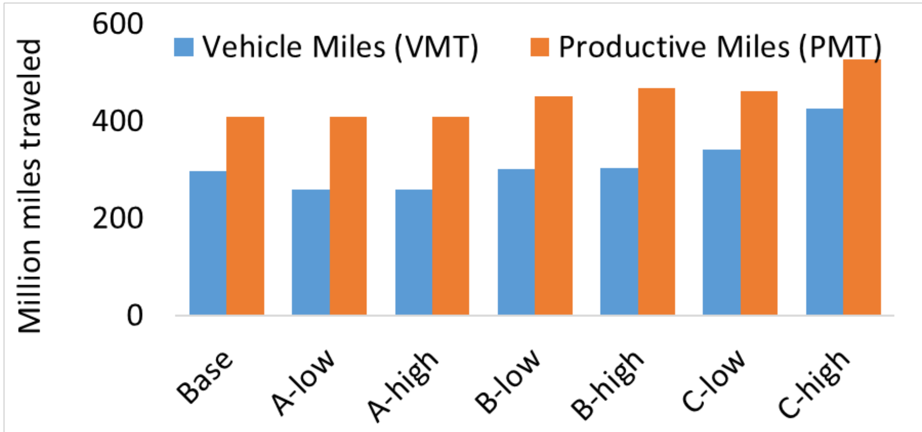
OUTPUT VISUALIZATION TOOLS
STATIC

POLARIS (Maps)

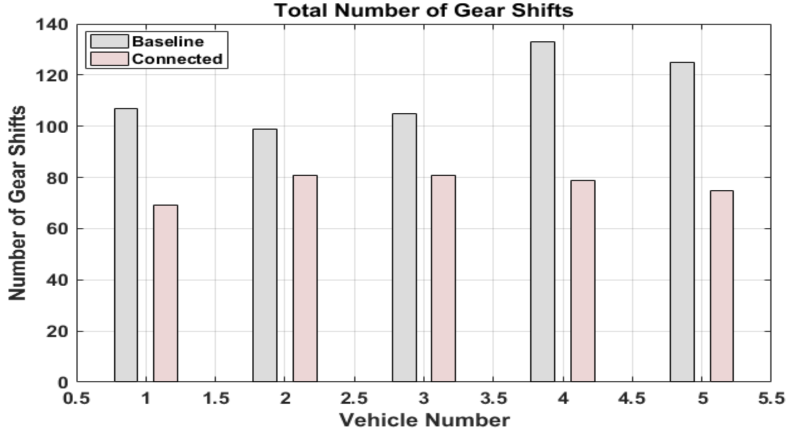


SVTrip (Vehicle Trip Profile)

POLARIS (Results)



RoadRunner
(Component Operating Conditions)



OUTPUT VISUALIZATION TOOLS
DYNAMIC

From entire metropolitan areas to individual vehicles

RoadRunner + CARLA

POLARISGL

TECHNICAL ACCOMPLISHMENTS AND PROGRESS
BASELINE SCENARIO

DETAILED CHICAGO MODEL INCLUDES TRANSPORTATION INFRASTRUCTURE AND LAND USE

Transit network

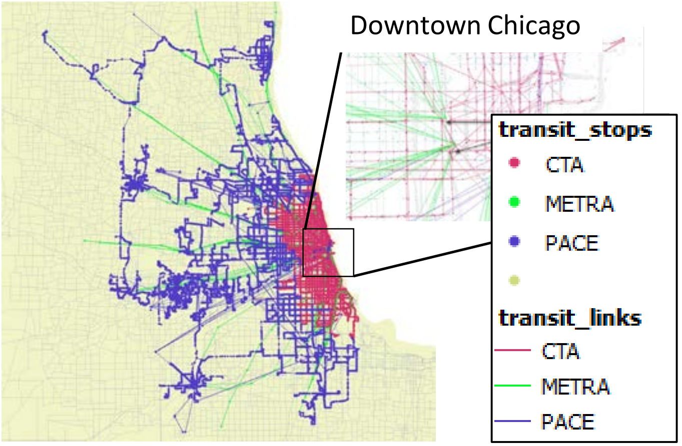
- 35,077 nodes (CTA, PACE, METRA)
- 217,119 links (including auto network)
- 344 transit routes with 2,098 transit patterns
- 28,138 transit vehicle trips
- Intermodal and walking connections

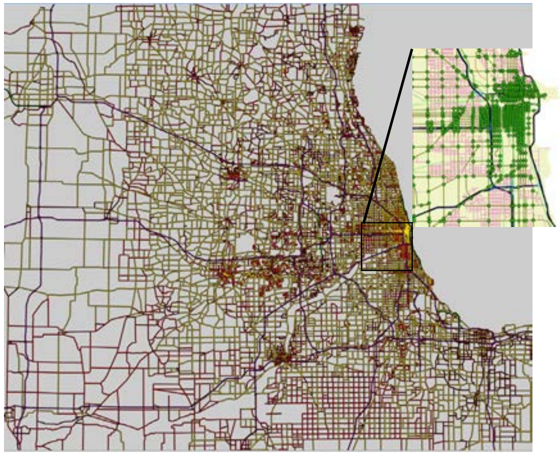
Street network

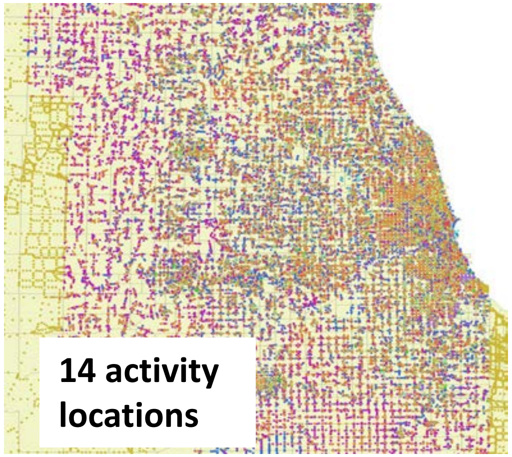
- 31,000 links with 18,900 nodes
- 7,900 traffic signals
- 12,500 stop signs
- 32.8 million trips (27 million by auto)

Demand

- 470,000 individual activity locations
  - Associated with activity types
  - Form start/end point for trips
- 270,000 parking locations with cost and capacity
- 10.2MM persons in 3.8MM HH

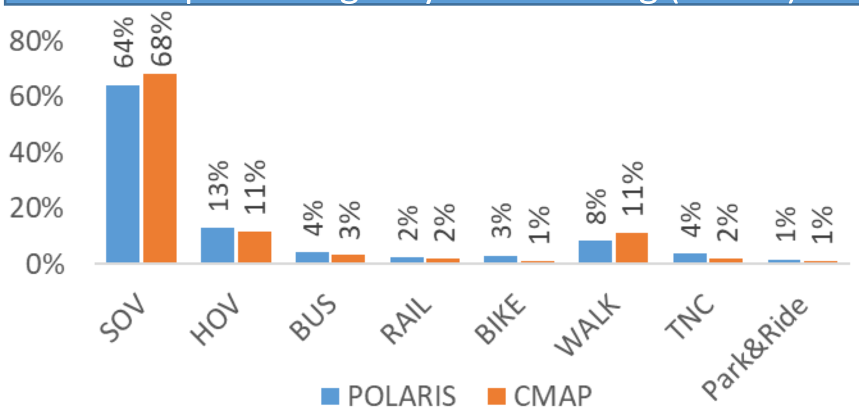




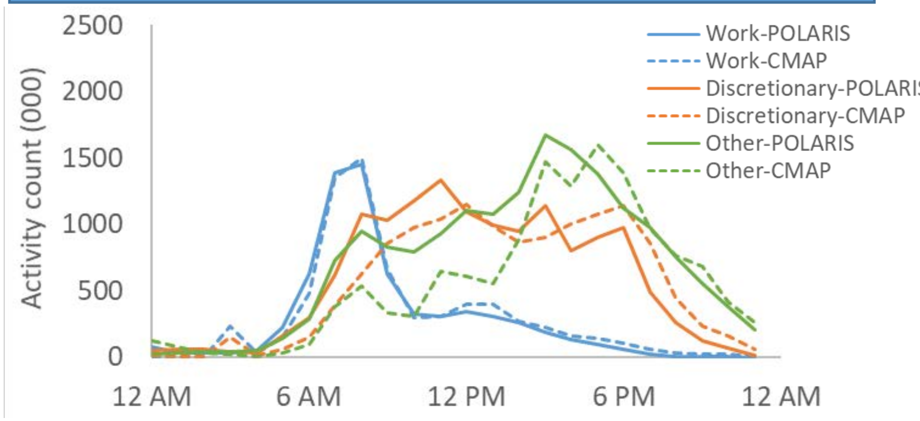


CHICAGO BASELINE MODEL HAS BEEN CONTINUOUSLY CALIBRATED/VALIDATED SINCE 2012

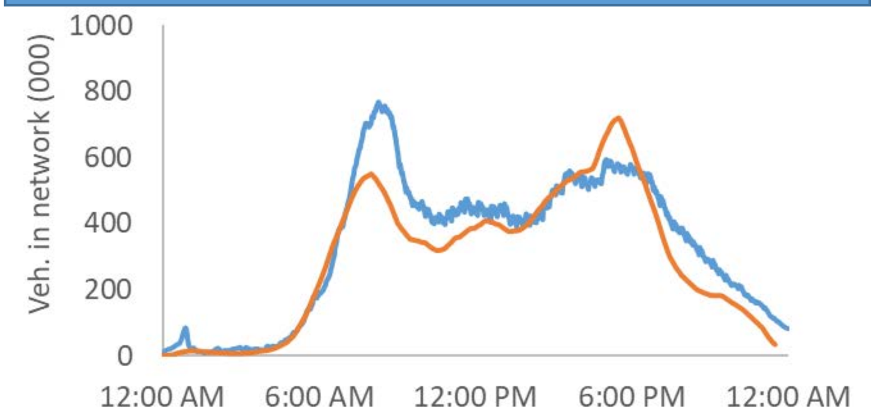
Mode shares closely matched to Chicago Metropolitan Agency for Planning (CMAP)



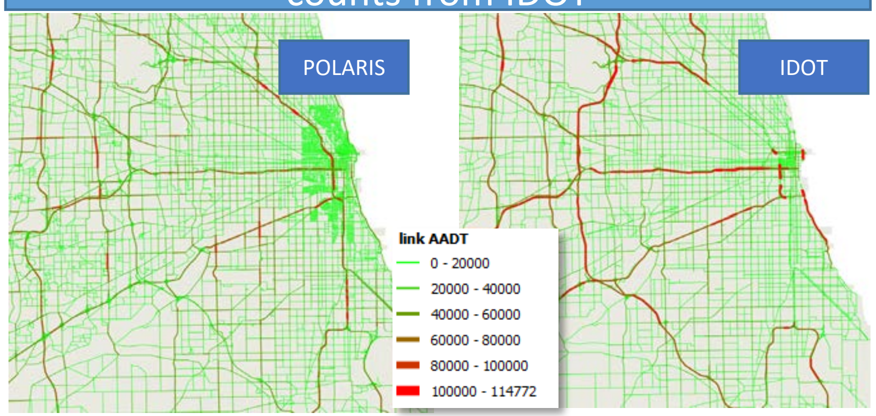
Activity counts & start times are similar to CMAP as well



In-network curves are very sensitive to model differences

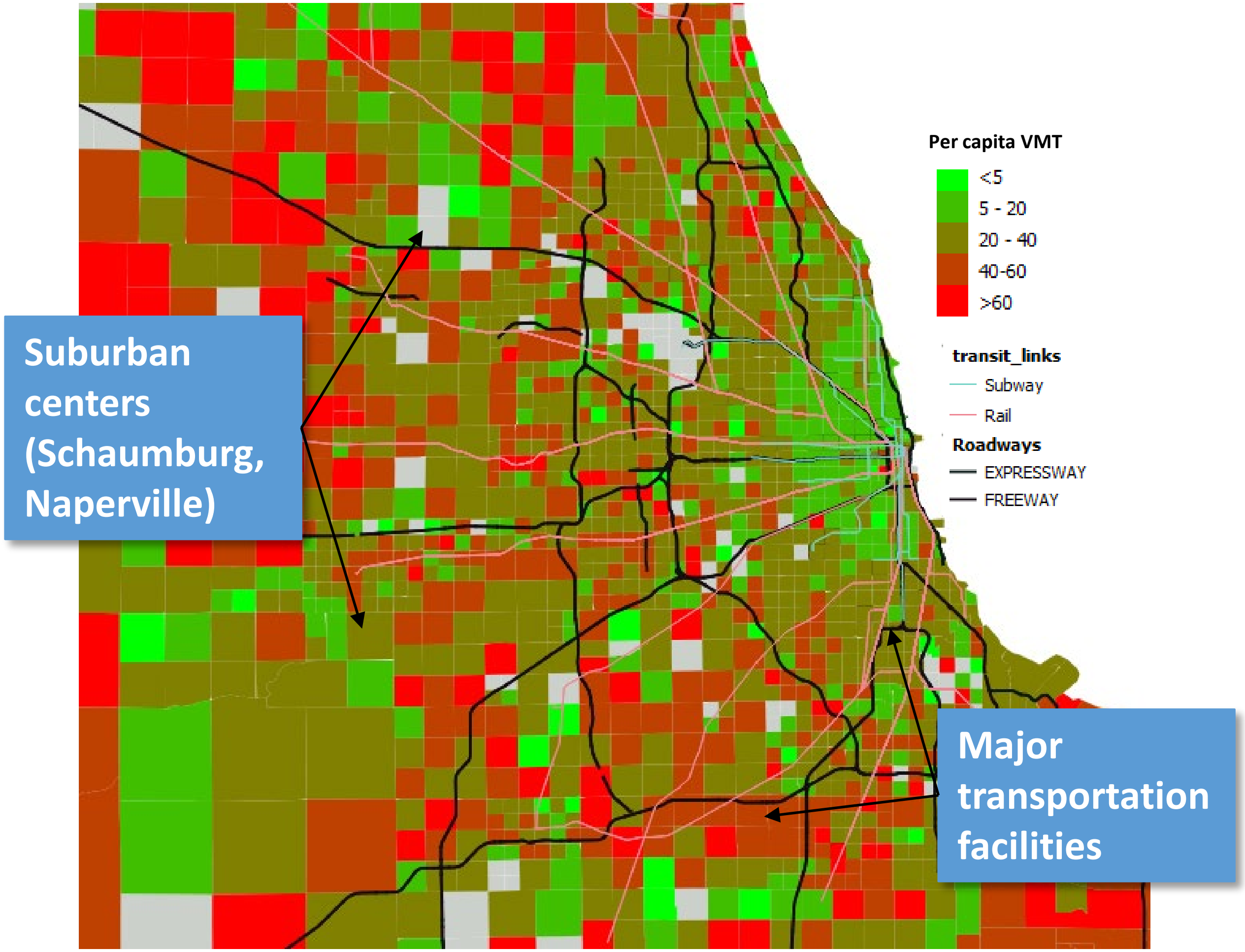


Simulated traffic counts compare closely to counts from IDOT



SOV – Single Occupancy Vehicle
HOV – High Occupancy Vehicle
TNC – Transportation Network Company
CMAP – Chicago Metropolitan Area Planning

VMT ON A PER CAPITA BASIS MUCH HIGHER IN SUBURBAN/RURAL AREAS AND AREAS WITH POOR ACCESSIBILITY



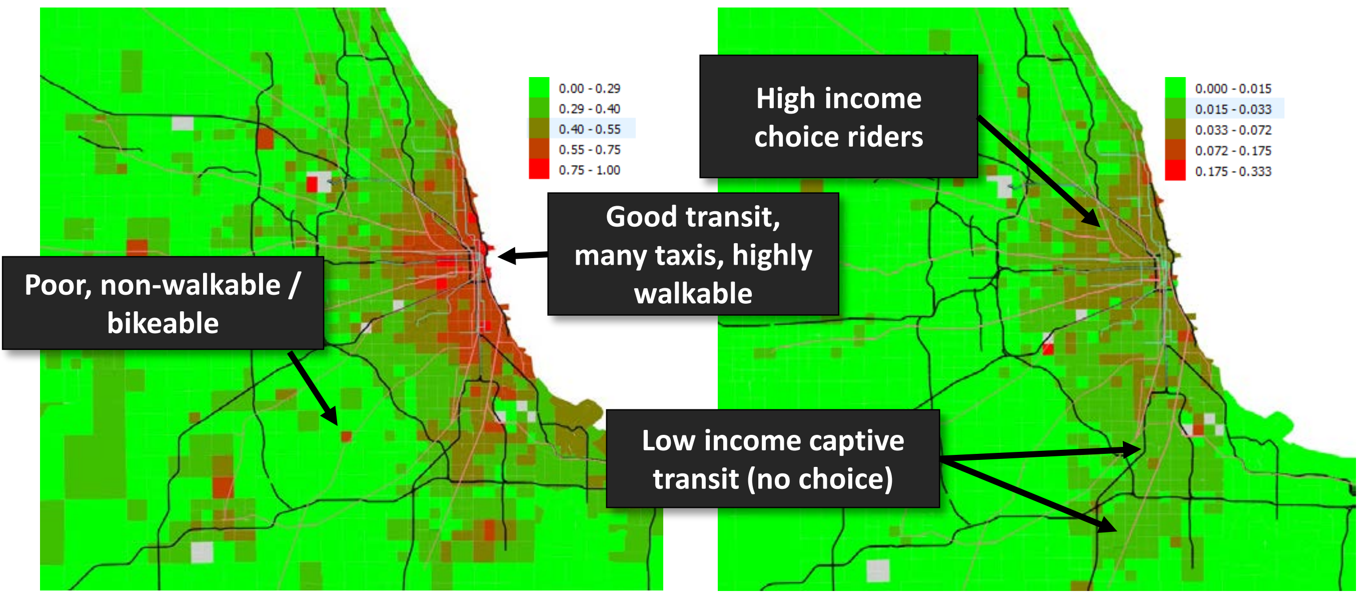
- VMT aggregated by home location of all travelers
- Much higher in areas away from major rail and interstate facilities
- Higher in areas further away from Chicago CBD
- There are multiple suburban pockets of lower average travel – polycentric Chicago Business Districts (CBDs)

MODE SHARES VARY SUBSTANTIALLY ACROSS THE REGION DEPENDING ON MANY FACTORS

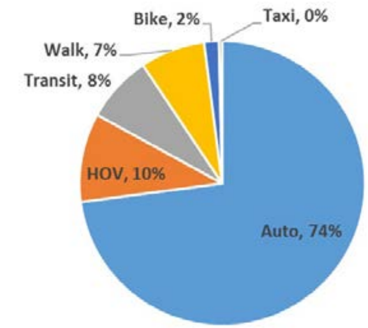
Trip purpose, home accessibility, socio-demographics,…

Non-auto mode share by home zone

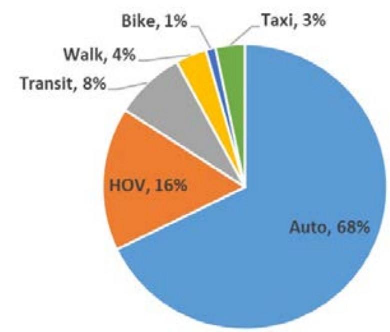
Transit mode share by home zone



Work trips



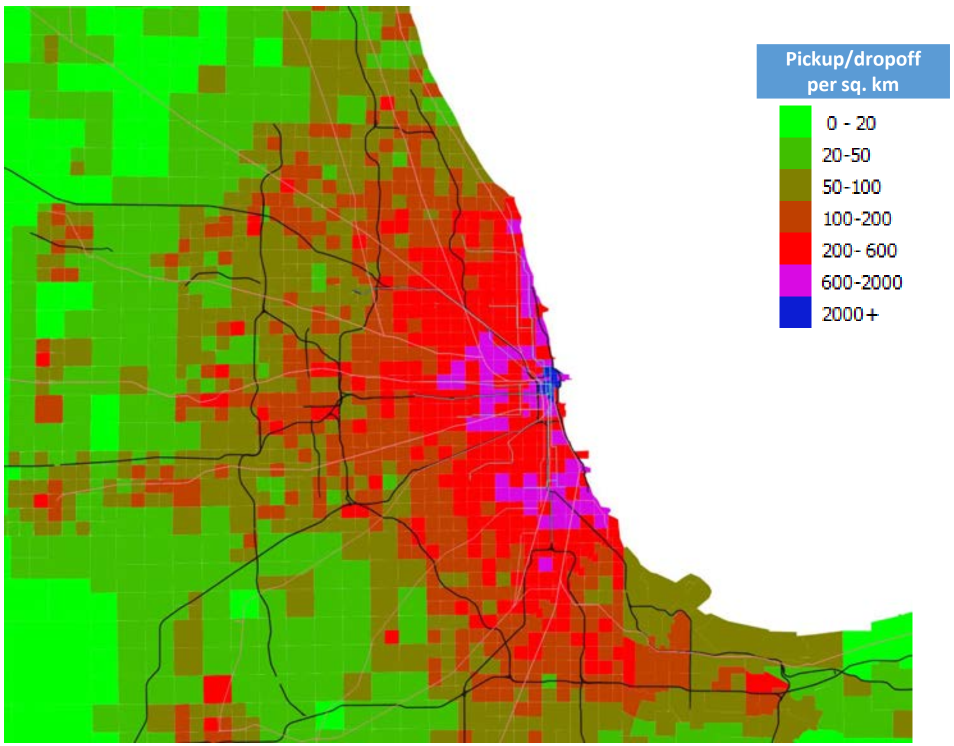
Non-work trips



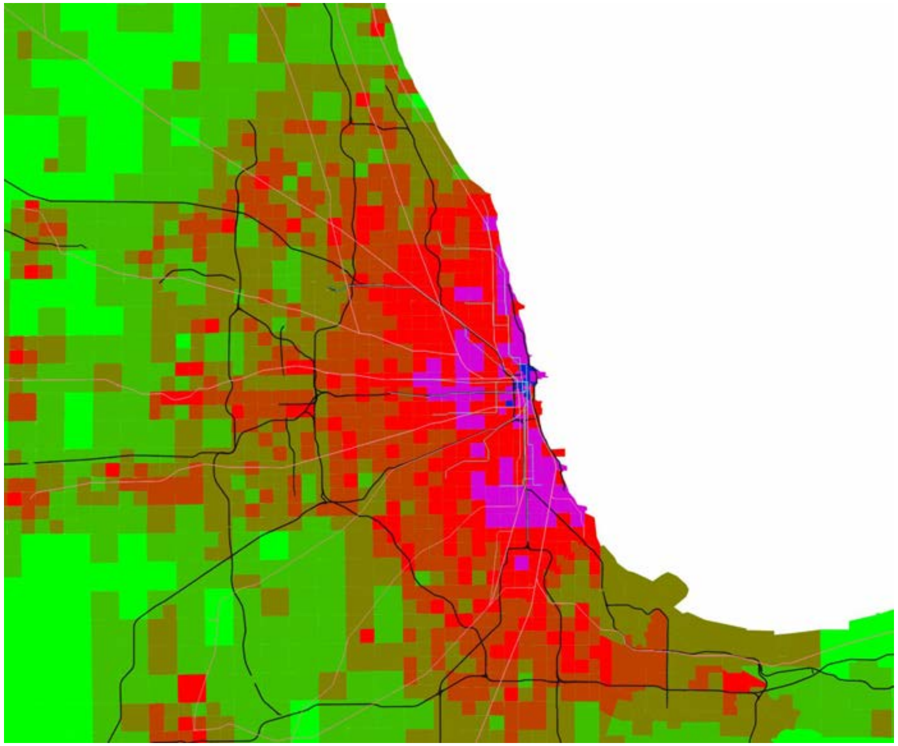
TNC DISTRIBUTION

Pickup & Dropoffs concentrated downtown but still many occur in the suburbs

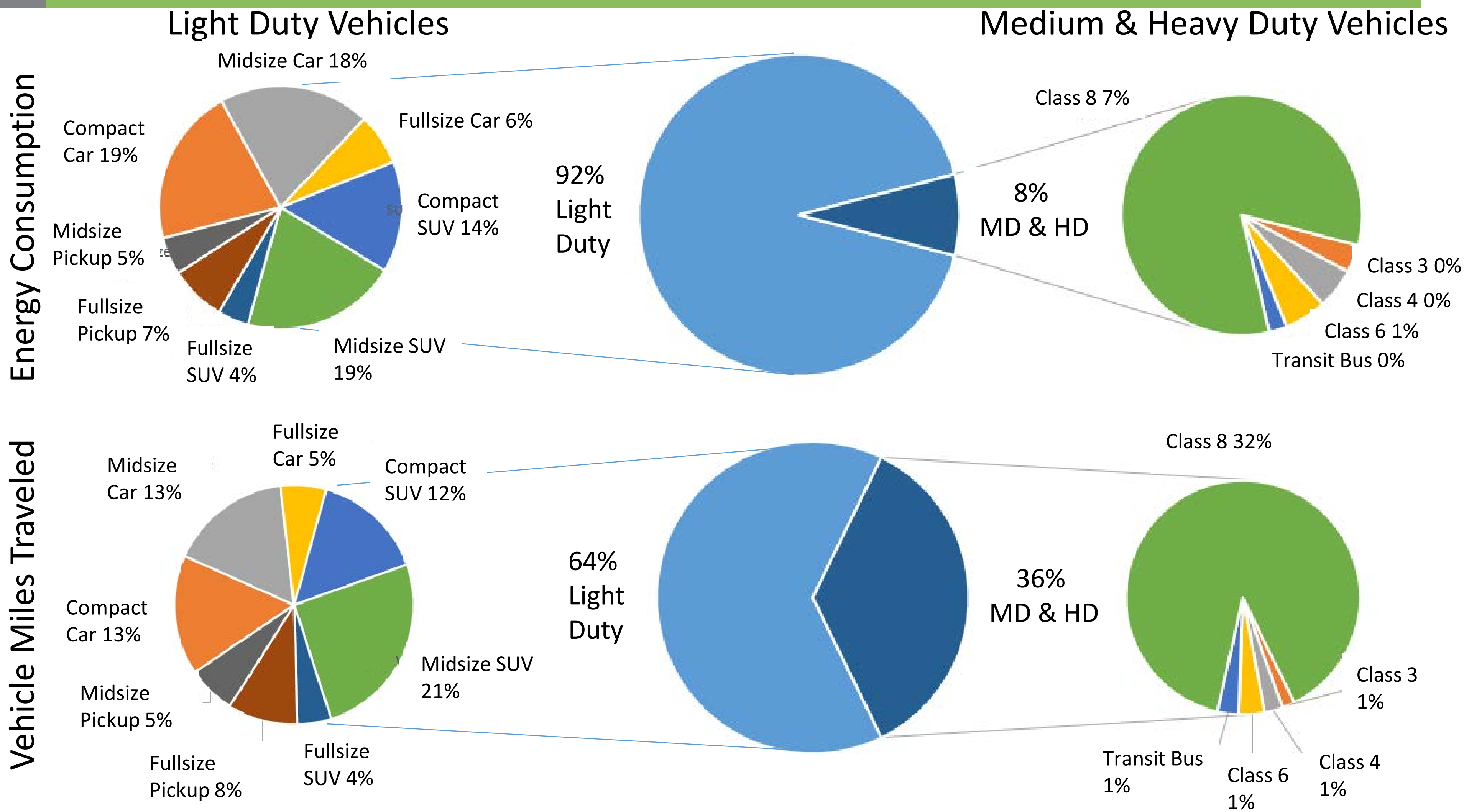
Total TNC pickups



Total TNC dropoffs



MD/HD ACCOUNT FOR SMALL PORTION OF VMT BUT A SIGNIFICANT PORTION OF ENERGY CONSUMED



TECHNICAL ACCOMPLISHMENTS AND PROGRESS
RESULTS OVERVIEW

MULTIPLE SCENARIOS CONSIDERED (BASELINE + 3 FUTURES)

Sharing is Caring (A)

New technology (I.e., integrated Apps) enables people to significantly increase the use of transit, **car sharing** and multi-modal travel. **Partial automation** is being introduced mostly on the highway system.

Technology Takes Over (B)

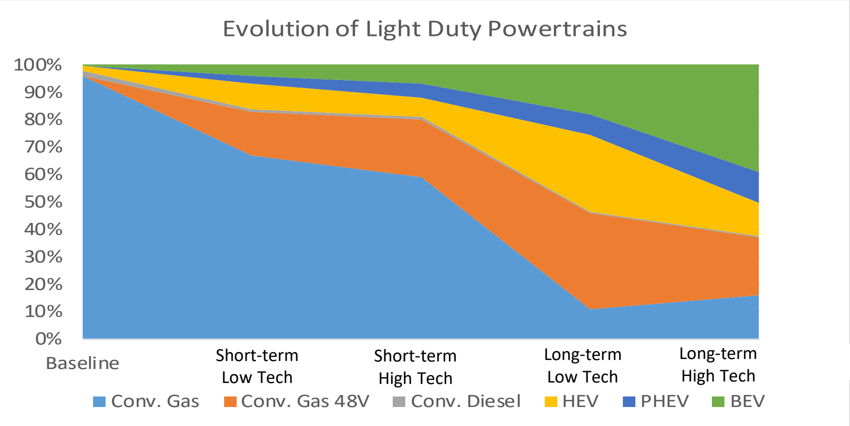
Technology has taken over our lives, enabling a **high usage of ride sharing and multi-modal trips** as they are convenient affordable. As a result, private ownership has decreased, **e-commerce** is common as is **telecommuting.**

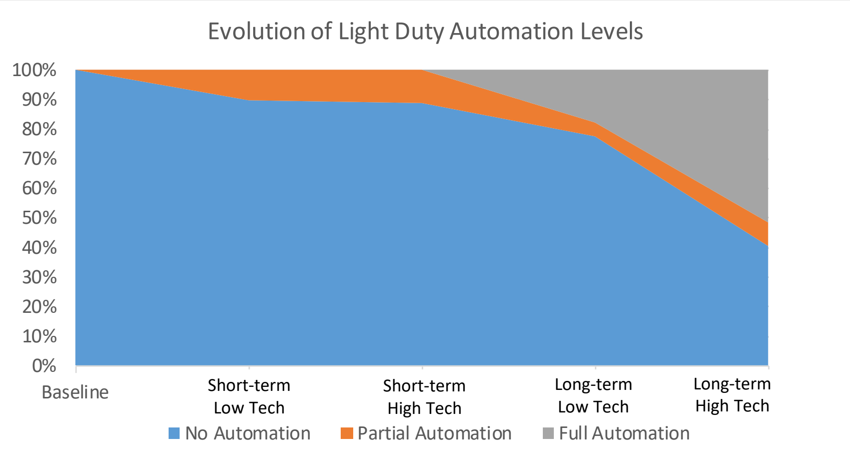
All About Me (C)

Fully automated vehicles within households are common with personal ownership resulting in **low ride sharing market**. The ability to own AVs leads to **lower e-commerce** and alternative work schedules, and feeds into urban sprawl.

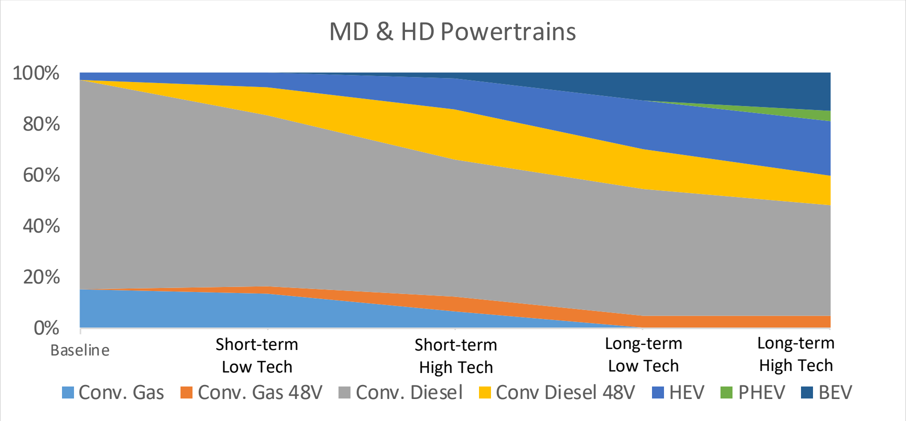
VEHICLE FLEET ASSUMPTIONS

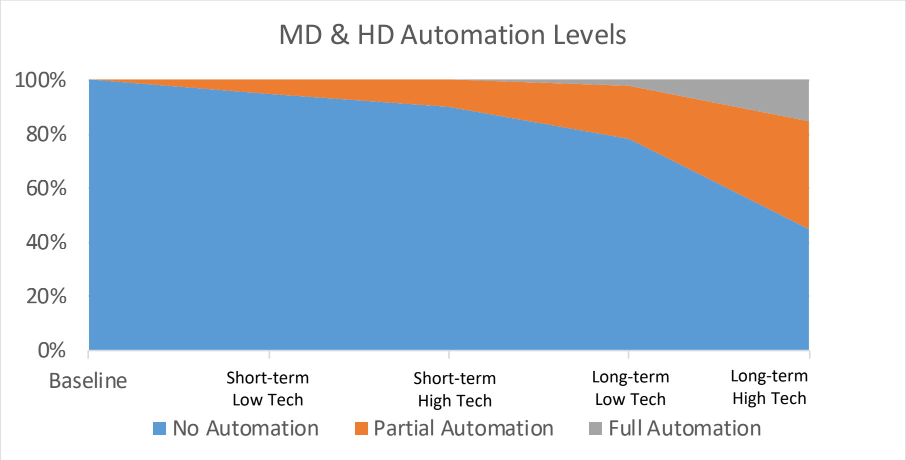
Light Duty Vehicles





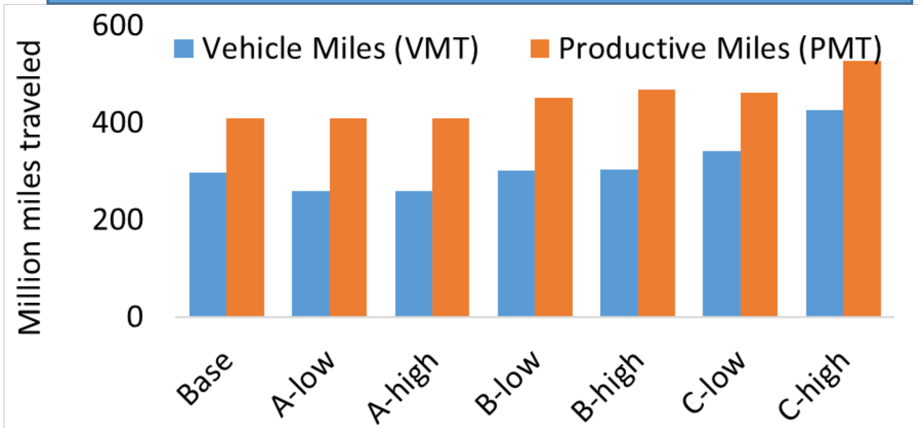
Medium & Heavy Duty Vehicles



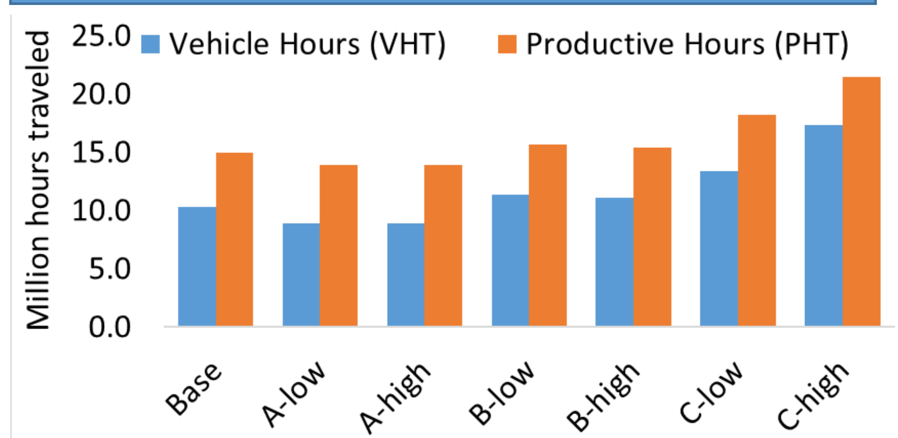


POLARIS MODEL RESULTS: PRIVATE AV LESS EFFICIENT THAN SHARED FLEETS FOR REGIONAL ENERGY AND MOBILITY

Vehicle and Productive[1] Miles Traveled

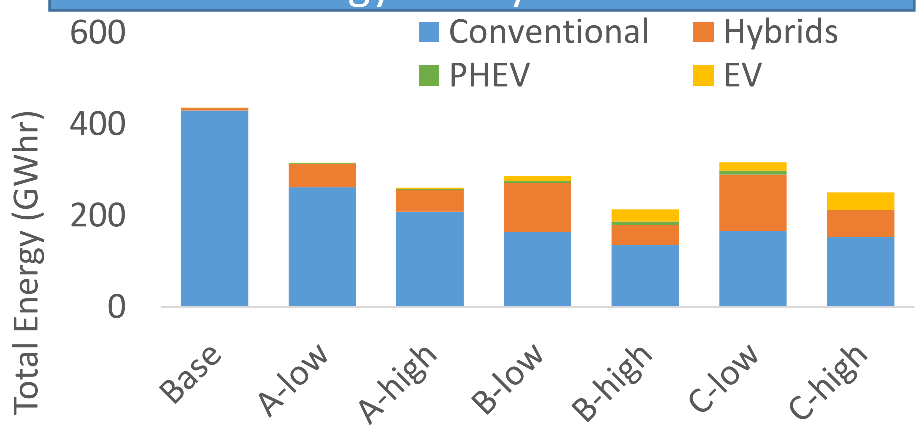


Vehicle and Productive Hours Traveled

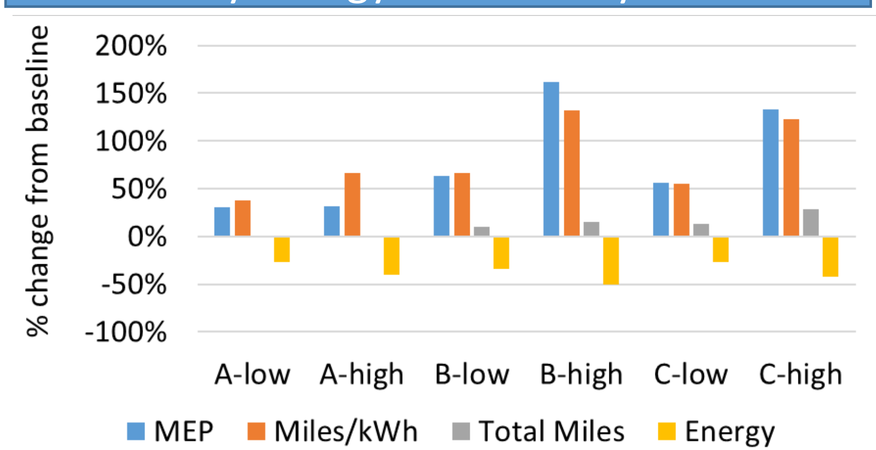


1. Productive miles includes all vehicle miles used to move people or goods (excludes unloaded travel miles)

Energy use by scenario



Mobility Energy Productivity metrics



A – Sharing is caring
B – Technology takes over
C – All about me

Low – Vehicle business as usual
High – VTO Targets

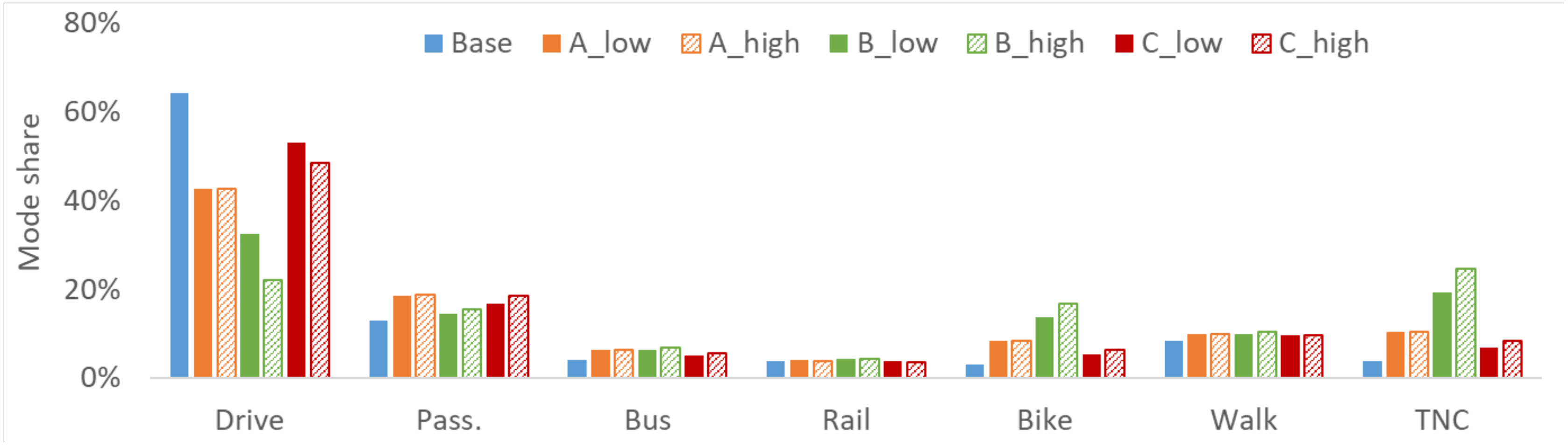
U.S. DEPARTMENT OF ENERGY SMARTMOBILITY Systems and Modeling for Accelerated Research in Transportation

Argonne NATIONAL LABORATORY | INL Idaho National Laboratory | BERKELEY LAB | OAK RIDGE National Laboratory | NREL NATIONAL RENEWABLE ENERGY LABORATORY

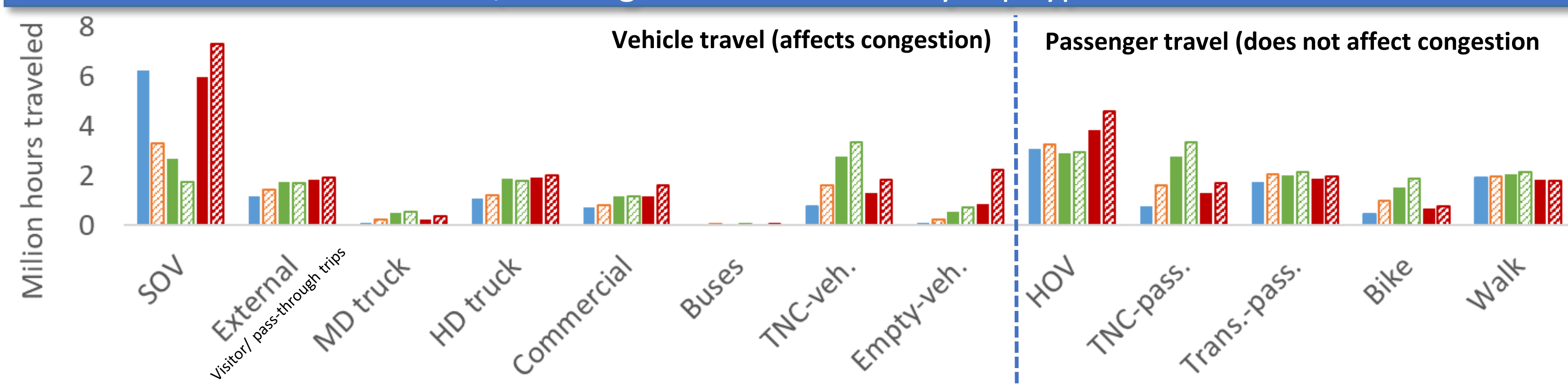
CHANGES TO MOBILITY AND ENERGY ARE LARGELY DRIVE BY MODE SHIFTS AND SHIFT TO E-COMMERCE

EEMS017, EEMS60, EEMS77

Mode share by Scenario



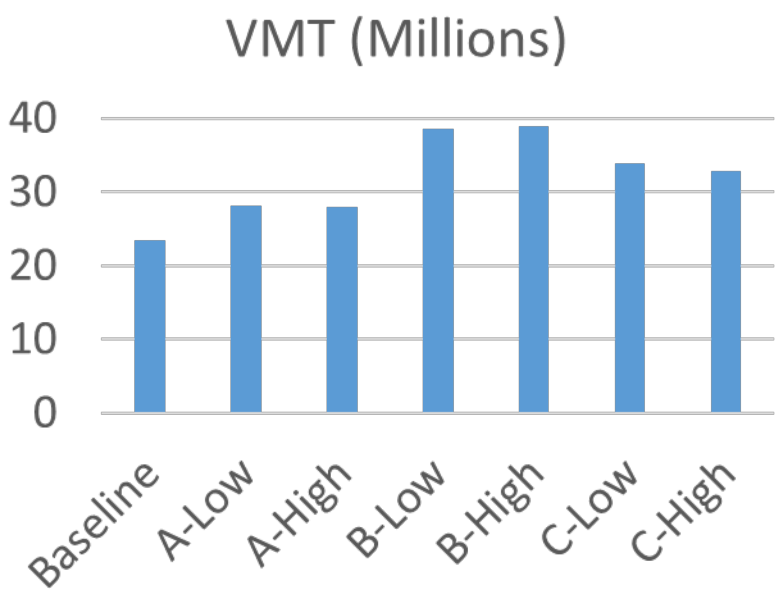
Vehicle/Passenger hours of travel by trip type and mode

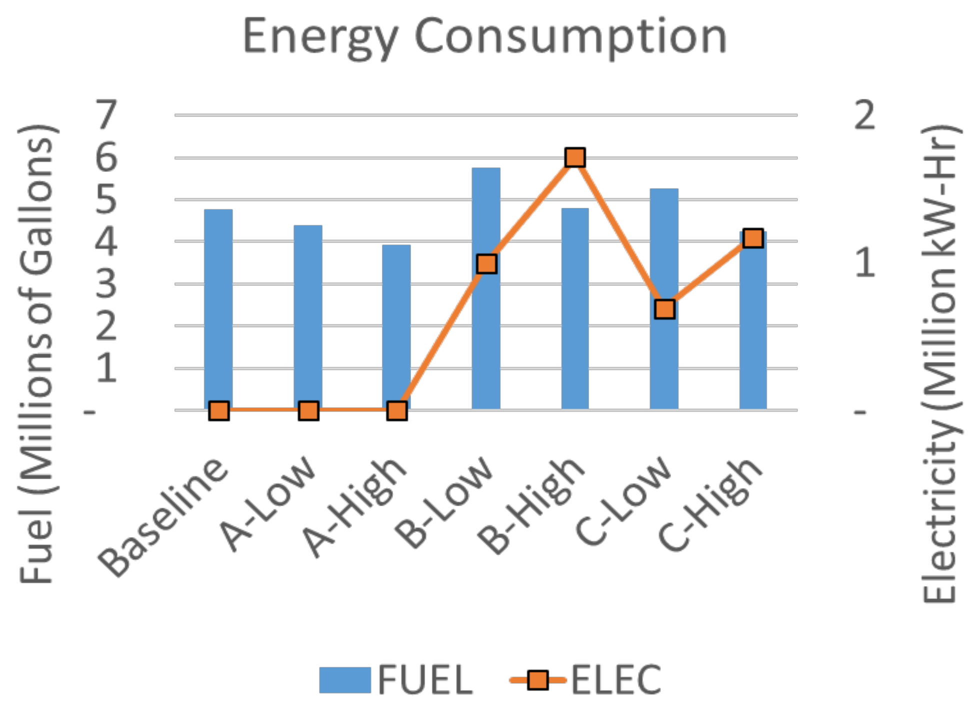


A – Sharing is caring
B – Technology takes over
C – All about me

Low – Vehicle business as usual
High – VTO Targets

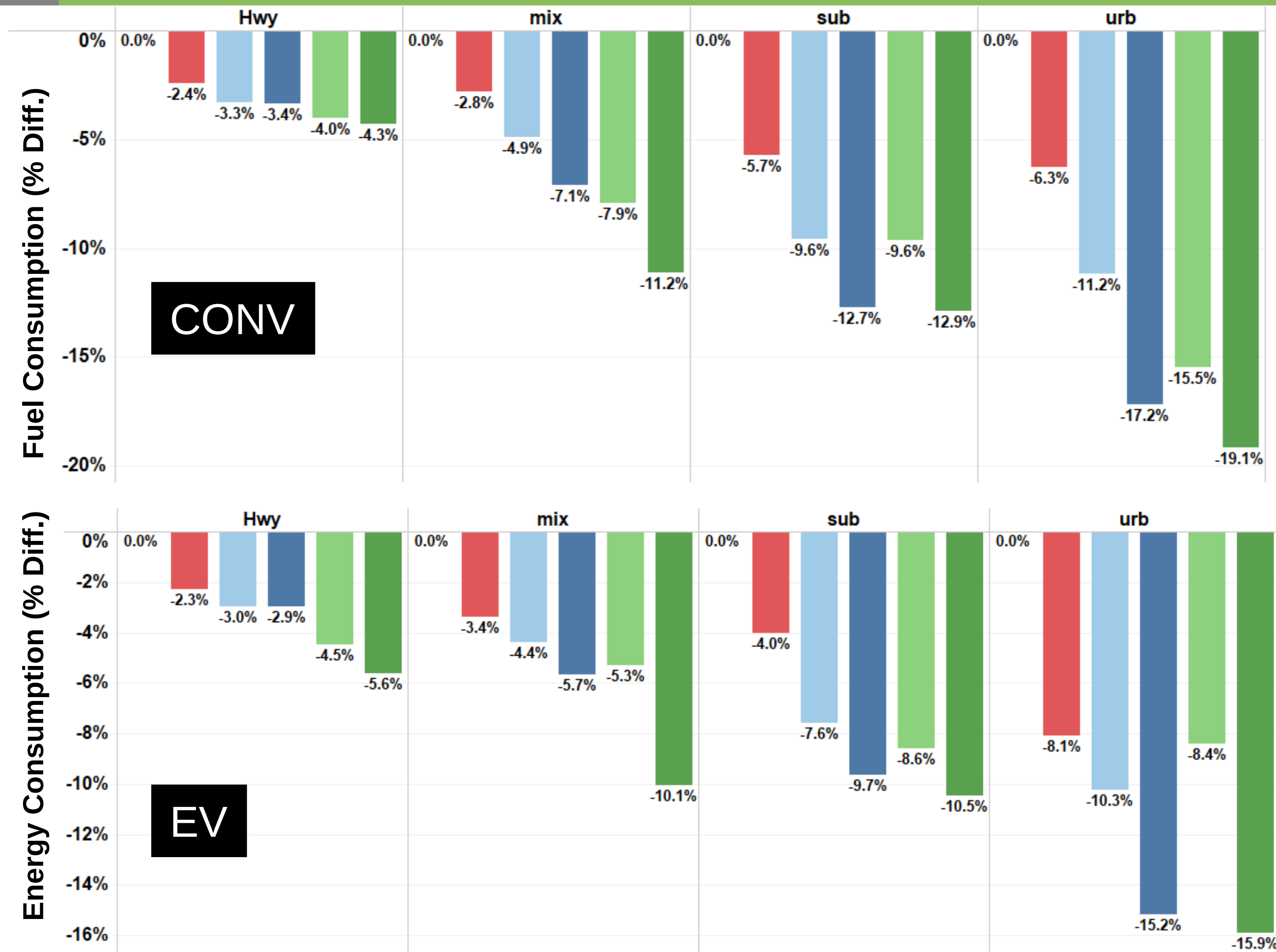
E-COMMERCE, COMMODITY FLOWS DRIVE INCREASE IN TRUCK VMT IMPROVED TECHNOLOGY REQUIRED TO MITIGATE FUEL CONSUMPTION





Scenarios—commodity flow growth:	Scenarios—household delivery rate:
• A: Moderate • B & C: High	• Baseline: ~1 delivery per week • A & B: 7 deliveries per week • C: ~3-4 deliveries per week

INDIVIDUAL CAV ECO-DRIVING VEHICLE CONTROL KEY TO ENERGY SAVINGS



Control
- Baseline
- Baseline + V2I
- EcoDrv Spd/Accel
- EcoDrv Spd/Accel + V2I
- EcoDrv PT+Spd
- EcoDrv PT+Spd + V2I

ROAD RUNNER

Key assumptions
Simulation over 44 real-world routes, highway, mixed, suburban and urban
Misdsize car with current technology, conventional and BEV200
Baseline = Baseline, no optimization EcoDrv Spd/Accel = Eco-driving control with Speed/Acceleration Optimization EcoDrv PT+Spd = Eco-driving control with Powertrain and Speed Optimization
V2I = eco-approach with V2I communications
Results shown for lead vehicle, compared to baseline

RESPONSE TO PREVIOUS YEAR REVIEWERS' COMMENTS

- The project was not reviewed previously

PARTNERSHIPS AND COLLABORATIONS

U.S. DEPARTMENT OF ENERGY SMARTMOBILITY Systems and Modeling for Accelerated Research in Transportation	EEMS013, EEMS016, EEMS017, EEMS020, EEMS023, EEMS031, EEMS034, EEMS035, EEMS057, EEMS060, EEMS068, EEMS075, EEMS076, EEMS077, EEMS078, EEMS079
TEXAS A&M UNIVERSITY	Improvement of CAV traffic flow model using CAV-specific fundamental diagrams
THE UNIVERSITY OF TEXAS AT AUSTIN	Shared Automated Vehicle (SAV) fleet modeling
UNSW SYDNEY	Traveler behavior – Value of Travel Time
THE UNIVERSITY OF ILLINOIS AT CHICAGO UIC	Activity scheduling and resource allocation
UCIRVINE	TNC modeling
UNIVERSITY OF MICHIGAN	Real-world vehicle energy use used to develop the Machine Learning Model

REMAINING CHALLENGES AND BARRIERS

- Improve the implementation of each model interaction
  - RoadRunner <-> Aimsun <-> POLARIS
  - EVI-PRO <-> POLARIS
  - UrbanSim <-> POLARIS
  - Freight Demand <-> POLARIS
- When possible, further develop models to have similar level of fidelity, otherwise use translators
- Continue to validate the workflow with additional tools

PROPOSED FUTURE RESEARCH

- Automate the process to support iterative simulations
- Implement and deploy processes with AMBER
- Keep improving computational efficiency (HPC deployment, convergence)

POLARIS

AUTONOMIE

ROADRUNNER

SVTRIP

Linux OS
Distributed & Parallel HPC
Optimization / Control
No 3rd party license when possible

SUMMARY – UNIQUE IMPLEMENTATION

- Includes numerous partners (5 labs, 8 universities) each contributing unique expertise:
  - LBNL (micro-sim, on-road data, land use)
  - NREL (charging station location)
  - ORNL (parcel freight demand)
  - INL (EV charging)
  - LLNL (aerodynamics)
  - Univ. Calif Irvine (TNC repositioning)
  - George Mason Univ. (optimization/calibration)
  - Univ. Illinois@Chicago (activity scheduling and choice)
  - Texas A&M (CAV traffic flow model)
  - Texas @ Austin (SAV fleet modeling)
  - Rensselaer Polytechnic Inst. (freight)
  - Univ. NewSouthWales (value of travel time)
  - Washington State Univ. (TNC driver decision)

- Smart Workflow

Integrated

- >10 partners
- > 12 tools
  - VTO Benefit/Targets
  - Includes economic impact
  - Linkage with Life Cycle Analysis tools (GREET)

High Fidelity

- 100% agents simulated
- Representative vehicle models (VTO)
- Includes stop signs & traffic lights
- Enables vehicle speed dynamic
- Accurate energy consumption for each technology
- Component operating conditions

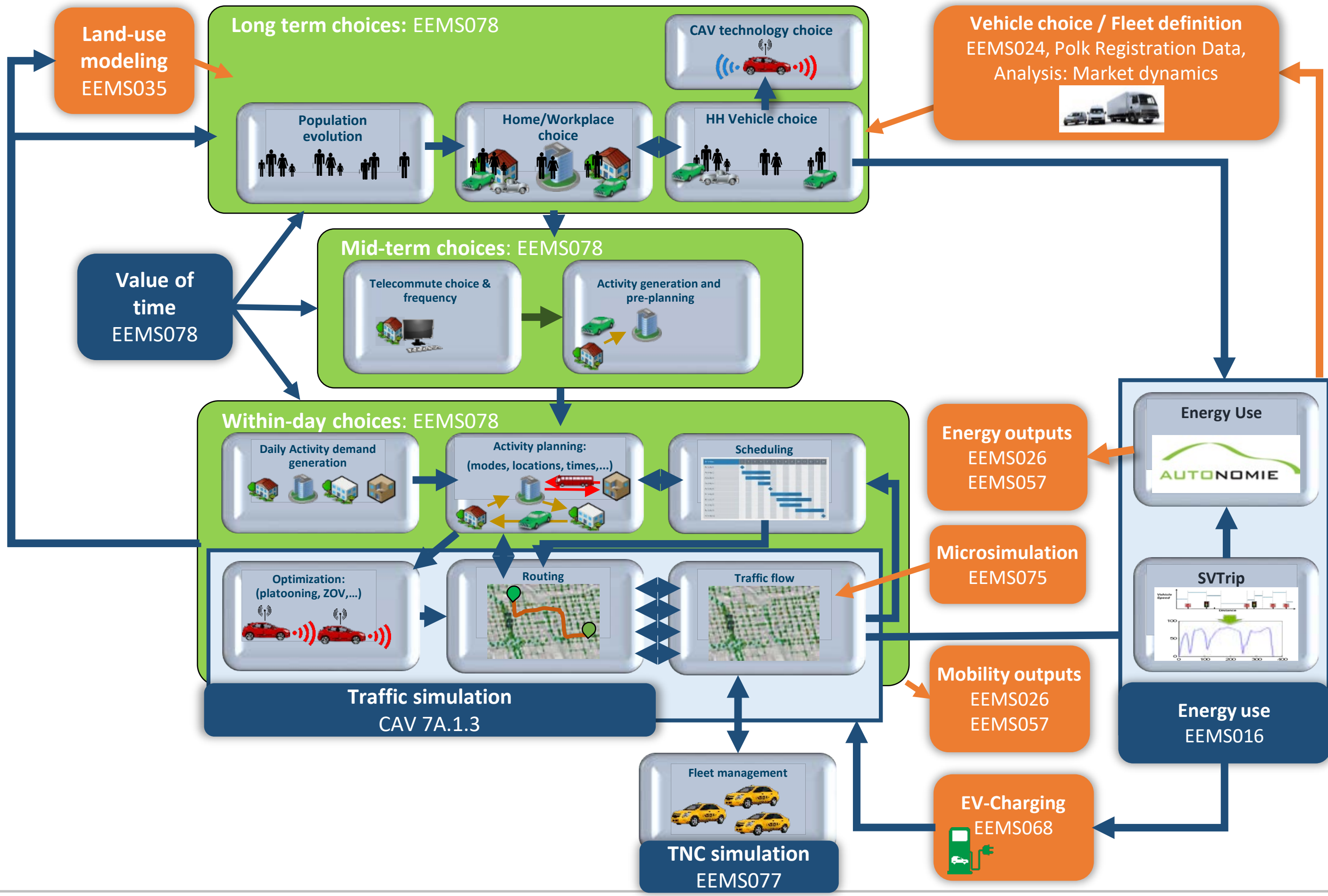
Computationally Efficient

- ~4h for 10M agents
- Entire process deployed with HPC

QUESTIONS?

TECHNICAL BACK-UP SLIDES

POLARIS: AGENT-BASED ACTIVITY-TRAVEL SIMULATION MODEL SIMULATES REGIONAL MOBILITY



Polaris Highlights:

- Simulate **regional** mobility
- Provides detailed travel information by each **agent**
- Fully **integrated** demand, dynamic traffic assignment, and simulation
- Integrated with **energy** model for regional energy analysis
- **Open-source** C++ for Windows/Linux
- Supports **HPC**
- 4-8 hr for 10M agents

Inputs from:	EEMS016, EEMS023, EEMS024, EEMS035, EEMS075
Used in:	EEMS013, EEMS017, EEMS058, EEMS060, EEMS077,EEMS078
Outputs to:	EEMS026, EEMS035, EEMS057, EEMS068

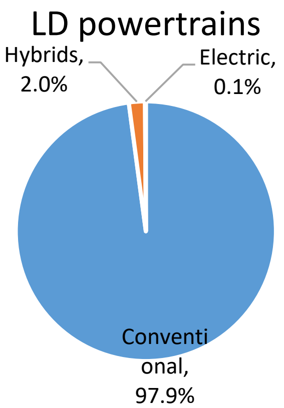
U.S. DEPARTMENT OF ENERGY SMARTMOBILITY

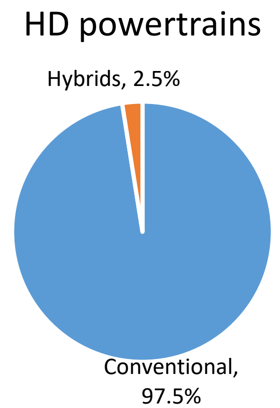
Argonne NATIONAL LABORATORY · INL Idaho National Laboratory · BERKELEY LAB · OAK RIDGE National Laboratory · NREL NATIONAL RENEWABLE ENERGY LABORATORY

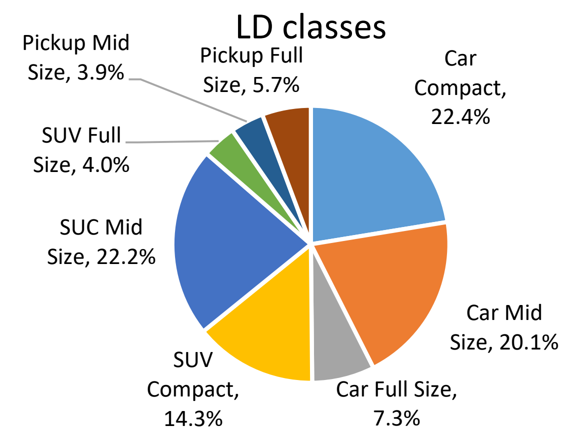
BASELINE FLEET COMPOSITION

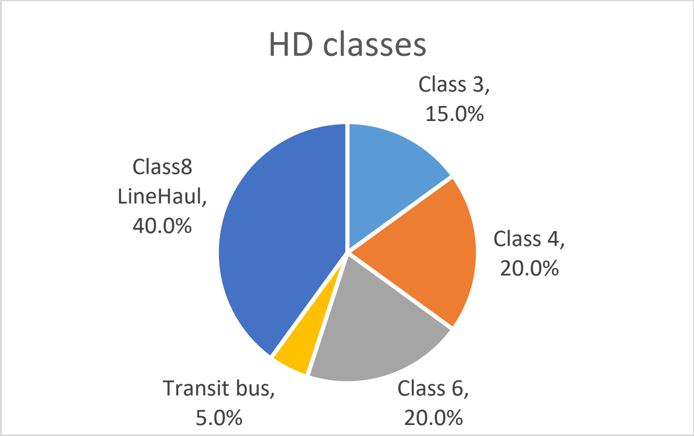
Consistent w/ POLK and IEA

CAR_COMPACT-Gas-Conventional	21.2%
CAR_COMPACT-Gas-HEV	1.2%
CAR_MID_SIZE-Gas-Conventional	19.6%
CAR_MID_SIZE-Gas-HEV	0.5%
CAR_FULL_SIZE-Gas-Conventional	7.3%
SUV_COMPACT-Gas-Conventional	14.2%
SUV_COMPACT-Gas-HEV	0.1%
SUV_MID_SIZE-Gas-Conventional	22.0%
SUV_MID_SIZE-Gas-HEV	0.2%
SUV_FULL_SIZE-Gas-Conventional	4.0%
TRUCK_FULL_SIZE-Gas-Conventional	5.7%
TRUCK_MID_SIZE-Diesel-Conventiona	1.9%
TRUCK_MID_SIZE-Gas-Conventional	2.0%
Class3Box-Gas-Conventional	13.0%
Class3Shuttle-Gas-Conv	2.0%
Class4Delivery-Diesel-Conventional	20.0%
Class6P&D-Diesel-Conventional	20.0%
TransitBus-Diesel-Conventional	2.5%
TransitBus_Diesel-HEV	2.5%
Class8_LineHaul-Diesel-Conventional	40.0%





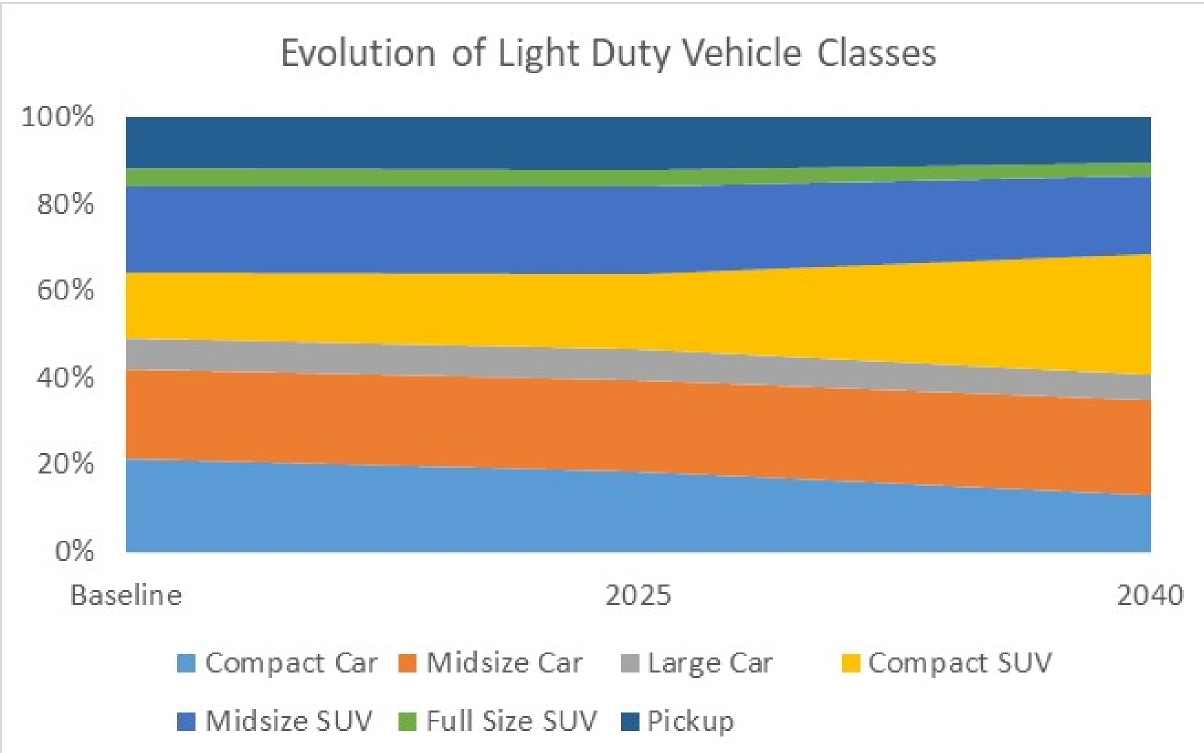




U.S. DEPARTMENT OF ENERGY SMARTMOBILITY Argonne NATIONAL LABORATORY INL Idaho National Laboratory BERKELEY LAB OAK RIDGE National Laboratory NREL

EVOLUTION OF VEHICLE CLASSES

Light Duty Vehicles



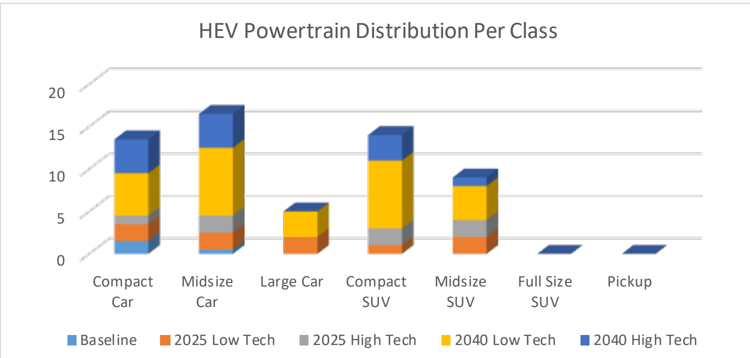
Compact SUV market increase over time at the expense of passenger cars. Trend consistent with IEA

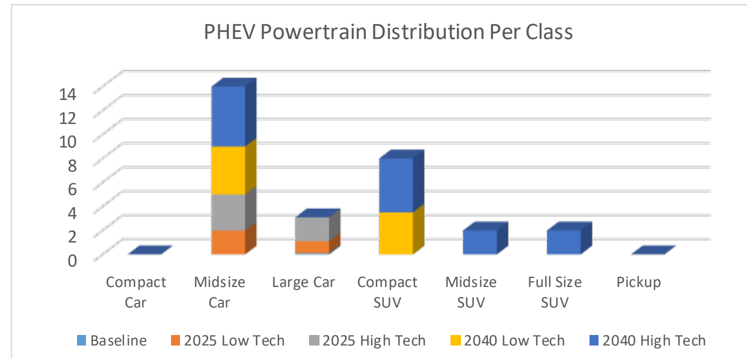
Medium & Heavy Duty Vehicles

Maintained current classes marked distribution constant

VEHICLE FLEET UPDATED

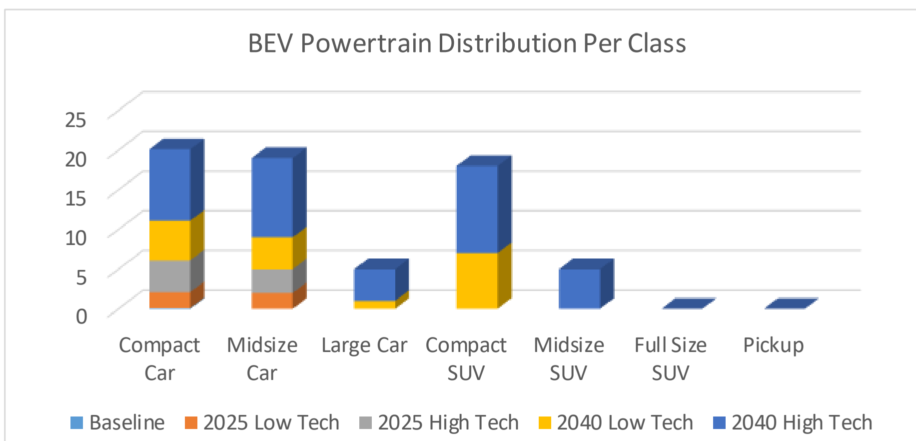
Light Duty Vehicles Electrification





- HEVs expected to penetrate the SUV market along with midsize car

- PHEVs predominant for midsize car



- BEVs significant for compact car as well as SUVs

PARAMETERS UPDATED/ADDED

Automation Distribution within Private and Fleet Light Duty Vehicles

	Variables	Baseline	(A) High sharing low automation	(B) High tech - mobility	(C)Low sharing high Automation
	Private Ownership	Current vehicle ownership based on POLK & current population by ZIP code	Low	Low	High
	Shared Use	1.3	1	1	1.3 (vehicle with driver) - 1.6 (vehicle without driver
	VOTT (Car mode only)	1	High (see table below)	Low (See table below)	Low (See table below)
	Propensity non-car modes	1	0.5	1	1
	Propensity telecommute	0.8 days per month	11.2 days per month	11.2 days per month	3.5 days per month
	E-Commerce	0.08 deliveries per person-day	0.5 deliveries per person-day	0.5 deliveries per person-day	0.2 deliveries per person-day
	Long Haul Commodity Flow	1% CAGR	1% CAGR	1.3% CAGR	1.3% CAGR
	Land use density	2017 Land Use	2017 Land Use	Long term planning (2050)	Urban sprawl
LDV privately owned	Non-Automated	98%	75% (low tech) / 74% (high tech)	41.5% (low tech) / 37.5% (high tech)	72.5% (low tech) / 35.5% (High tech)
	L3/4	0%	5% (low tech) / 6% (high tech)	5% (Low Tech) / 8% (High tech)	5% (Low Tech) / 8% (High tech)
	L5	0%	0%	0%	12.5% (Low tech) / 41.5% (High tech)
LDV fleets (taxi, TNC)	Non-Automated	2%	15%	36% (low tech) / 3% (high tech)	5%
	L3/4	0%	5%	0%	0%
	L5	0%	0%	17.5% (low tech) / 51.5% (high tech)	5% (low tech) / 10% (high tech)

Parameter not used for scenario

New parameters added to improve consistency

Decided to use 2017 Land Use for all scenarios for AMR