Exponential growth in global PEV sales:
- EV sales exceeded 10 million in 2022
- EV share is more than tripled in three years, from 4% in 2020 to 14% in 2022
- ~14 million in sales by the end of 2023, representing ~18% of total car sales

Charging is a major concern for potential PEV buyers:
- Recent survey shows that 6 in 10 Americans who aren’t yet sold on PEVs were concerned about where and when they would charge (61%) and how far that charge will take them (55%), i.e., “range anxiety”.
- Early charging patterns are home-dominant (>80% of charging) but many future PEV owners may not have access to a home charger.
Background and Motivation

- EV charging a priority for federal government:
  - By 2030, 50% of LDV sales as ZEV, 500,000 PEV chargers
  - 2021 Bipartisan Infrastructure law includes $7.5 billion to build out a national network of EV chargers
  - 2022 Inflation Reduction Act provides federal tax credits for EV infrastructure, EV purchases, and domestic mining and manufacturing.

**Major Uncertainty**: EV charging infrastructure requirements are hard to predict over time; challenging to plan for…

**Our Solution**: Data-driven EV charging demand modeling and charging infrastructure planning
Data-Driven EV Charging Demand Modeling

- **Passenger EVs:**
  - National Household Travel Survey (NHTS) data
  - Real-world connected vehicle trip data
  - Land use data
  - Vehicle registration and EV adoption prediction

- **Electric Transit Buses:**
  - General Transit Feed Specification (GTFS) data
  - Electric bus deployment prediction
  - Energy consumption prediction
Passenger EVs

1. Trip Data Acquisition & Preprocessing
Representative LDV travel data for region(s) of study is joined with geographically determined locational characteristics obtained from multiple data sources.

2. EV Adoption Modeling
For a given analysis year (2040), assign PEVs to households by vehicle model (battery size, ECR, & max kW acceptance required for simulation).

3. Travel Itinerary Synthesis
Vehicle trips from data aggregators typically do not contain persistent vehicle identifiers enabling analysis of multi-trip travel itineraries. Thus, an approach for generating synthetic travel itineraries is leveraged.

4. EV Charging Simulation
EV charging is simulated for synthetic travel itineraries considering: 1) EV adoption assumptions; 2) charging behaviors and location-specific EVSE availability; 3) home charging access assumptions.

5. EV Load Profile Generation
Charging demand for a given analysis year (2040) is assigned to specific locations (i.e., land parcels) by location type.
Real-World Driving Data Set:
- Vehicle trips data acquired from Wejo for two months in the state of Virginia.
  - ~3% of passenger vehicle population
  - September 2021 and February 2022
  - Richmond, VA and Newport News, VA regions
- Trip O/Ds joined to land use data to infer trip purpose.

Regional Trip Data Summaries:

<table>
<thead>
<tr>
<th></th>
<th></th>
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<th></th>
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</tr>
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<tbody>
<tr>
<td>Newport News, VA:</td>
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<td>720k</td>
<td>4.3M</td>
<td>3.3M</td>
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<td>Newport News, VA:</td>
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<tr>
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<td>James City county</td>
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<td>1.3M</td>
<td>8.9M</td>
<td>7.2M</td>
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<tr>
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<td></td>
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<td></td>
</tr>
<tr>
<td>James City county</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Temporal scope: September 2021 (summer) February 2022 (winter)

Geographic scope: VA statewide

Google COVID-19 Community Mobility Reports
Passenger EVs

EV Adoption Modeling – NREL TEMPO Model:

- TEMPO is an all-inclusive transport demand model that projects household-level vehicle ownership and technology choices based on heterogenous consumer preferences.

- 2040 aggressive passenger EV adoption scenario assumes:
  - 50% national PEV sales by 2030
  - 100% national PEV sales by 2035

- TEMPO adoption outputs mapped to BEV/PHEV archetype vehicles
  - established for previous DOE projects

TEMPO Modeling Diagram

Archetype Vehicles for Simulation:

<table>
<thead>
<tr>
<th>Veh. Gen.</th>
<th>Vehicle Type</th>
<th>EV Range (mi.)</th>
<th>ECR (Wh/mi.)</th>
<th>DC Charge Accept. (kW)</th>
<th>2040 NN Fleet share (%)</th>
<th>2040 Rich Fleet share (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gen 3</td>
<td>BEV SUV/truck</td>
<td>300</td>
<td>475</td>
<td>575</td>
<td>37.5%</td>
<td>39.5%</td>
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<tr>
<td></td>
<td>BEV midsize car</td>
<td>300</td>
<td>325</td>
<td>400</td>
<td>7.8%</td>
<td>6.3%</td>
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<tr>
<td>Gen 2</td>
<td>BEV SUV/truck</td>
<td>250</td>
<td>475</td>
<td>350</td>
<td>10.8%</td>
<td>13.5%</td>
</tr>
<tr>
<td></td>
<td>BEV midsize car</td>
<td>300</td>
<td>325</td>
<td>300</td>
<td>3.3%</td>
<td>3.7%</td>
</tr>
<tr>
<td></td>
<td>BEV compact car</td>
<td>150</td>
<td>300</td>
<td>150</td>
<td>19.7%</td>
<td>17.8%</td>
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<tr>
<td>Gen 1</td>
<td>BEV SUV/truck</td>
<td>200</td>
<td>475</td>
<td>150</td>
<td>1.3%</td>
<td>2.2%</td>
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<td></td>
<td>BEV midsize car</td>
<td>275</td>
<td>300</td>
<td>150</td>
<td>0.6%</td>
<td>0.7%</td>
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<tr>
<td></td>
<td>PHEV SUV/truck</td>
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<td>9.7%</td>
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<td>PHEV midsize car</td>
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<td>3.2%</td>
<td>2.4%</td>
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<tr>
<td>Gen 0</td>
<td>BEV compact car</td>
<td>150</td>
<td>300</td>
<td>50</td>
<td>0.9%</td>
<td>0.8%</td>
</tr>
<tr>
<td></td>
<td>PHEV midsize car</td>
<td>20</td>
<td>250</td>
<td>N/A</td>
<td>4.3%</td>
<td>3.2%</td>
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</table>

https://www.nrel.gov/transportation/tempo-model.html

Mapping TEMPO PEV adoption to archetype vehicles for charging simulation.
Passenger EVs

Synthetic Vehicle Travel Itineraries:

- Wejo travel data contained unlinked trips with no persistent vehicle identifier, thus a procedure for generating synthetic travel itineraries (through trip chaining) was leveraged.

- Locational dwell distributions (from 2017 NHTS) are used to infer vehicle dwells at each stop. Trips are chained based on spatiotemporal alignment of trip origins and destinations (+ dwell).

- Synthetic vehicle travel itineraries are validated against 2017 NHTS vehicle trip distributions.

Example trip chain

Validation plots:
ZEP = synth veh itineraries
NHTS = ground truth
Passenger EVs

EV Charging Simulation – NREL EVI-Pro Model:

- EVI-Pro takes EV adoption and travel demand data and simulates EV charging behaviors, energy demands, and infrastructure requirements.

- For this study, EV drivers are assumed to prioritize home charging, followed by workplace and public slow charging (supported by real-world charging data).

- Home charging access is derived from previous modeling, 72% for the study region in 2040 scenario.

- 1-week charging demands are produced.

EVI-Pro ordered charge preference:

Home > Work > Public > L2 > Public DCFC

Drivers prefer destination charge during long dwell periods, maximizing opportunities for SCM...
Passenger EVs

EV Load Profiles:

- EV charging demand is combined from two sources:
  - **Intra-regional charging demand** is determined from EVI-Pro simulations
  - **Inter-regional charging demand** is determined by separately simulating charging for long-distance trips (>100-mi.) that end within the region of interest.

- EV charging events are assigned spatial coordinates depending on their location type:
  - **Home charging locations** = EV adoption projections + residential land use data.
  - **Workplace charging locations** = census tract of charging demand + commercial land use data.
  - **Public charging locations** = census tract of charging demand + commercial land use data.

- EV charging events can be assigned to individual stations depending on EVSE type(s), station size, and port utilization assumptions.
Complete Modeling Framework:

**Analysis Year**
- **Vehicle Types**
- **Owner Types**

**INPUT DATA**
- **Processing**
- **Intermediate Data**
- **RESULT**

**EV home locations**
- **EVI-Park**
  - Join trip O-Ds to locations
  - Survey Data (NHTS)

**EVI-ZEP**
- synthetic travel itineraries

**EVI-Pro**
- charging demand

**Charging Demand Database**
- Caldera/EVI-EnSite

**Grid Analysis**

**Outcome of this modeling**
- Park location
- Park start time
- Park end time
- Park start SOC
- Park end SOC
- Vehicle Type
- Charger Type
Electric Buses

- GTFS-based transit bus system analysis
- Transit system has relatively fixed routes and timetables, and its depot and terminal locations are known

```
Route shapes
Trip sequence
Stop times

TomTom road network
Map matching
Trained RouteE bus models
RouteE
Trip energy

Bus daily itinerary
Charging strategies
Depot and on-route charging facilities

Charging Simulation
Charging Demand Database
```

INPUT DATA
PROCESSING
INTERMEDIATE DATA
RESULT
Real-World Transit System Data:

- GTFS, General Transit Feed Specification or Google Transit Feed Specification, defines a common format for public transportation schedules and associated geographic information.
- A series of standardized, text files that can be easily shared, read, and used by anyone.
- Contains all information relating to the fixed schedules.
- Geospatial and scheduling information from “shapes”, “trips”, “stops”, and “stop times” files.
- Depot locations are from the National Transit Database (NTD).
- Deadhead trips from and to the depot and between trips are based on shortest path algorithm.
## Transit agencies:
- Williamsburg Area Transit Authority (WATA)
- Greater Richmond Transit Company (GRTC)
- Hampton Roads Transit (HRT)

<table>
<thead>
<tr>
<th>Transit Agency</th>
<th>Fleet Size</th>
<th>Routes</th>
<th>Weekday Blocks</th>
<th>Saturday Blocks</th>
<th>Sunday Blocks</th>
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<tr>
<td>WATA</td>
<td>20</td>
<td>13</td>
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<td>12</td>
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<tr>
<td>GRTC</td>
<td>142</td>
<td>38</td>
<td>110</td>
<td>81</td>
<td>63</td>
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<tr>
<td>HRT</td>
<td>294</td>
<td>71</td>
<td>293</td>
<td>236</td>
<td>136</td>
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</table>
Assumptions:

- Two electric bus options from Proterra

Simulation logic:

- Depot charging > terminal charging
- Smaller battery is better
- Lower charging power is better

<table>
<thead>
<tr>
<th>Model</th>
<th>Battery (kWh)</th>
<th>Efficiency (kWh/mi)</th>
<th>Range (mi)</th>
<th>Charging power (kW)</th>
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</thead>
<tbody>
<tr>
<td>ZX5 + 40-feet</td>
<td>492</td>
<td>1.8-2.5</td>
<td>160-240</td>
<td>150/180/450</td>
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<tr>
<td>ZX5 MAX 40-feet</td>
<td>738</td>
<td>1.9-2.8</td>
<td>220-340</td>
<td>150/180/450</td>
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</tbody>
</table>
# Electric Buses

## Winter Charging Energy

<table>
<thead>
<tr>
<th>Transit Agency</th>
<th>Depot Charging Energy (kWh)</th>
<th>Terminal Charging Energy (kWh)</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Weekday</td>
<td>Saturday</td>
</tr>
<tr>
<td>WATA</td>
<td>13358</td>
<td>11578</td>
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<tr>
<td>GRTC</td>
<td>36191</td>
<td>35125</td>
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<tr>
<td>HRT</td>
<td>117661</td>
<td>95267</td>
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## Summer Charging Energy

<table>
<thead>
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<th>Depot Charging Energy (kWh)</th>
<th>Terminal Charging Energy (kWh)</th>
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<tbody>
<tr>
<td></td>
<td>Weekday</td>
<td>Saturday</td>
</tr>
<tr>
<td>WATA</td>
<td>10647</td>
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<tr>
<td>GRTC</td>
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<tr>
<td>HRT</td>
<td>93914</td>
<td>74787</td>
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</table>
Electric Buses

Monday Charging Power Profile at Hampton Roads Transit's Depot

Monday Charging Power Profile at Hampton Roads Transit's Terminal 0454
Daily Charging Energy Needs for Opportunity Charging All Agency - Winter

Weekday

Saturday

Sunday
R-Shiny Based User-Friendly Dashboard
Next Steps and Key Challenges

- **Private vehicles:**
  - Higher resolution: more high-quality data
  - Higher fidelity: refine assumptions around EV user behaviors
  - Challenges: data availability and privacy issue

- **Medium/Heavy duty vehicles:**
  - Many vehicle types and *heterogenous vocational usage patterns*.
  - *Limited public or commercial data sets* capturing the full extent of M/HD operations.
  - High *uncertainty around technology adoption and timing*.
  - M/HD charging *models/approaches are less mature* than for passenger vehicles.
Thank you!