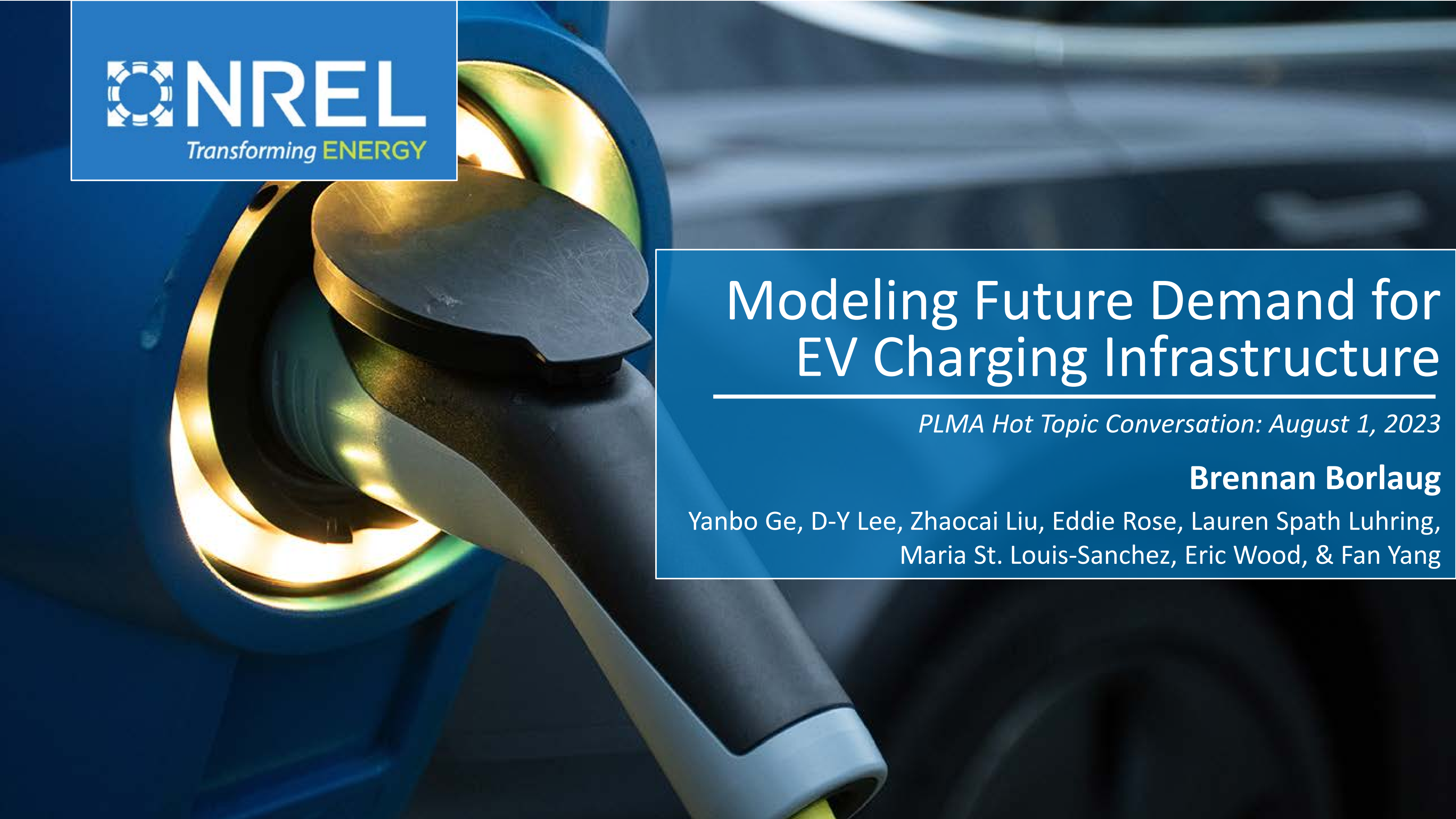


NREL Transforming ENERGY

Modeling Future Demand for EV Charging Infrastructure

PLMA Hot Topic Conversation: August 1, 2023

Brennan Borlaug

Yanbo Ge, D-Y Lee, Zhaocai Liu, Eddie Rose, Lauren Spath Luhring, Maria St. Louis-Sanchez, Eric Wood, & Fan Yang

U.S. DOE National Lab System

Largest U.S. National Laboratories

NREL
Transforming ENERGY

NREL at-a-Glance

~3,000

Workforce, including

~220 postdoctoral researchers

~60 graduate students

~80 undergraduate students

World-class

facilities, renowned technology experts

More than 900

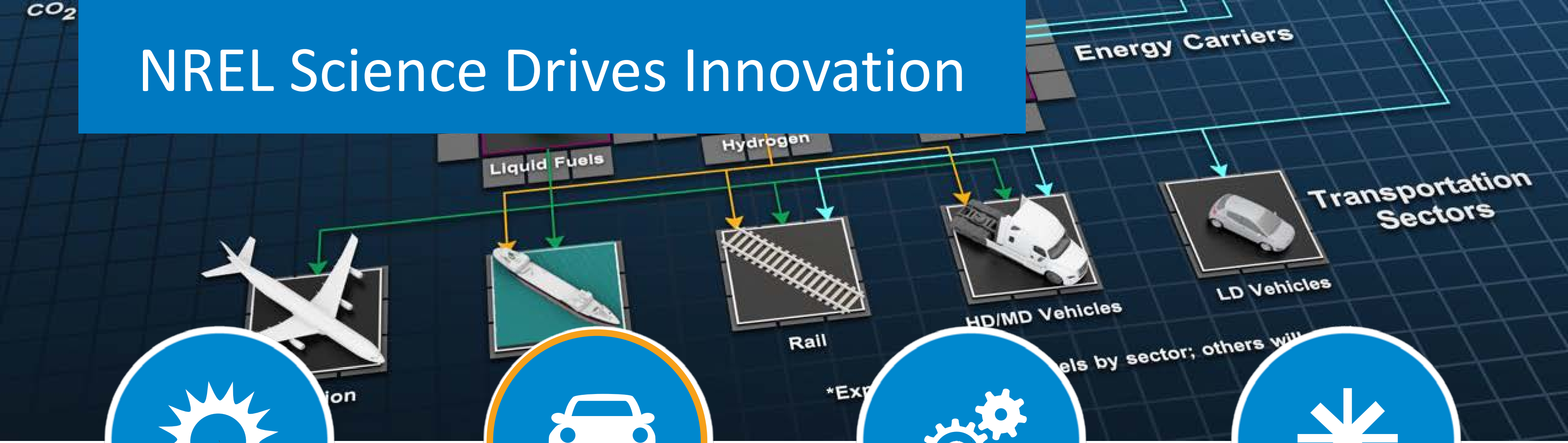
Partnerships

with industry, academia, and government

Campus

operates as a living laboratory

NREL Science Drives Innovation



Renewable Power

Solar

Wind

Water

Geothermal

Sustainable Transportation

Bioenergy

Electrification

Hydrogen

Energy Efficiency

Buildings

Advanced Manufacturing

Government Energy Management

Energy Systems Integration

Grid Integration

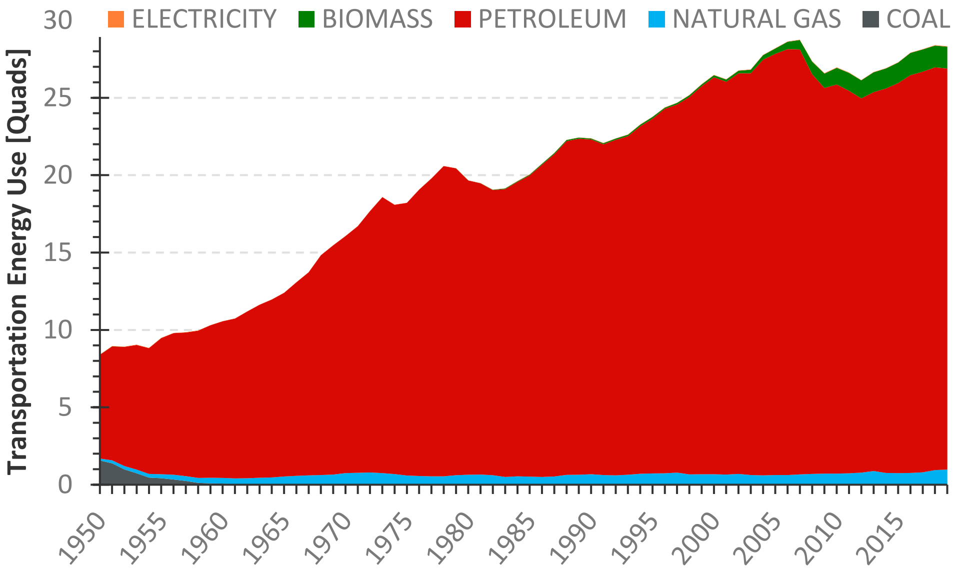
Hybrid Systems

Security and Resilience

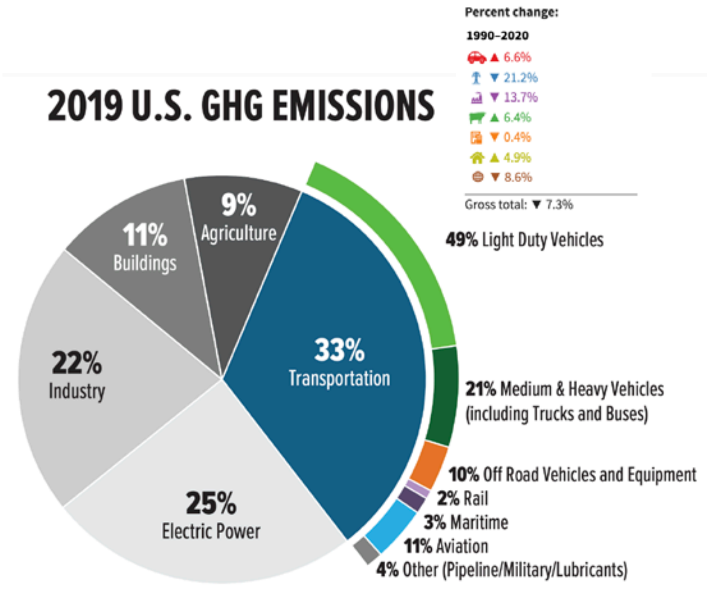
Contents

Transportation Systems are Petroleum Dependent…

Today, transportation is the **largest source of U.S. energy-related CO_2 emissions** in the United States and is responsible for ~70% of total petroleum use.



Source: NREL. Data from EIA Annual Energy Review



Source: DOE, 2023

…but the landscape is rapidly changing

Battery costs have declined 90% since 2010 with pack prices expected to be $100/kWh by 2026.

– *BloombergNEF (2022)*

U.S. EPA proposed rules to ensure that **two-thirds of new cars** and a **quarter of new heavy trucks** sold in the United States by **2032** are all-electric.

– *New York Times (2023)*

California **bans new combustion engine** cars starting in 2035.

– *Cal Matters (2022)*

Nearly 10% of global car sales were electric in 2021, four times the market share in 2019.

– *International Energy Agency (2022)*

2022 EV sales reached 19% in California, 79% in Norway.

– *Endgadget (2023)*

The **Inflation Reduction Act** will **reduce light-duty EV purchase costs by $3,400 to $9,050** from 2023-2032.

– *ICCT (2023)*

Amazon places an order for **100,000 electric delivery vans**, with thousands on the road today.

– *Business Insider (2022)*

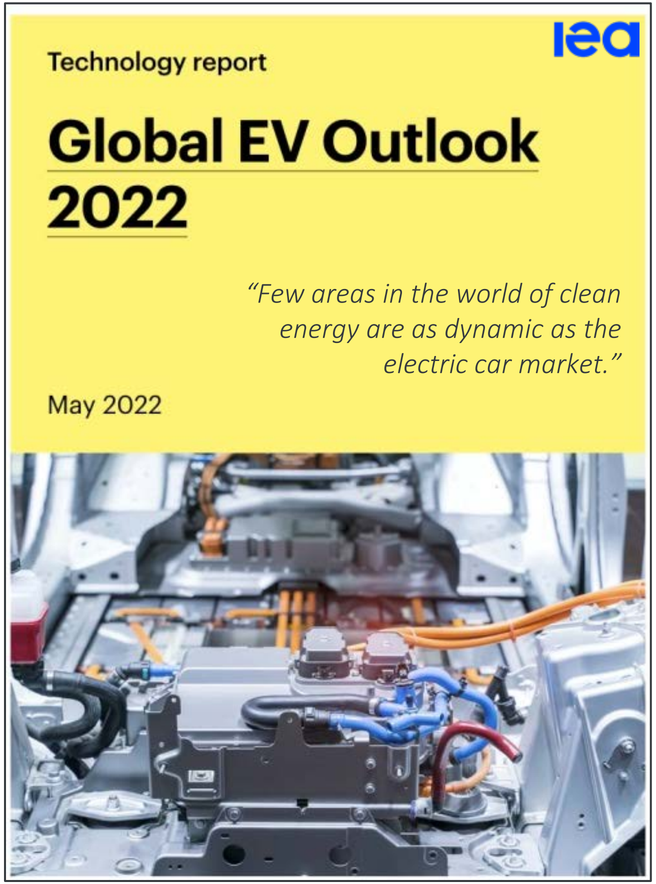
Six major **automakers to phase out new gas vehicles** by 2035 in leading markets.

– *Car and Driver (2021)*

Tesla delivers first **500-mile range electric semi trucks** to PepsiCo.

– *CNN (2022)*

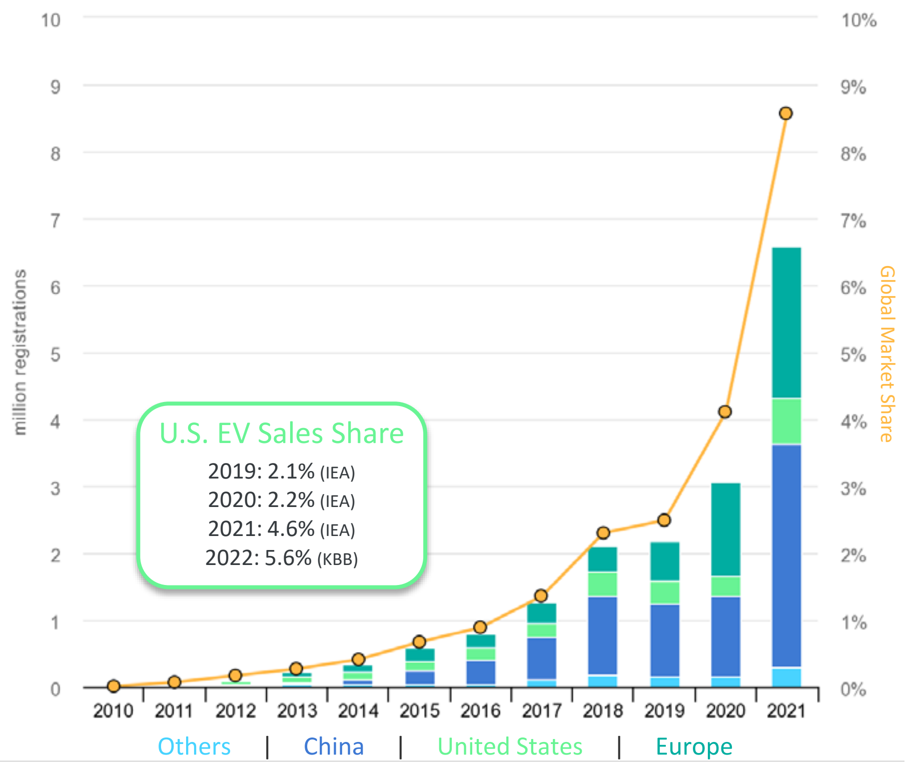
Electric Vehicles: a Success Story



- **Plug-in electric vehicles (PEVs*)** are experiencing a **rapid rise in popularity**:
  - Technology has matured; **Costs have declined**
  - **Supportive policies** for clean transportation have incentivized adoption and promoted awareness
  - **Automakers are bought in** with more model options being announced and becoming available
- PEVs offer a pathway to decarbonize on-road transportation when charged with **clean electricity**.
- Continued **rapid growth in PEV adoption** now expected for passenger vehicles as well as medium- and heavy-duty trucks and other applications (off-road, planes, ships, etc.).

**PEV and EV are used interchangeably in this presentation*

EV Sales are Growing...



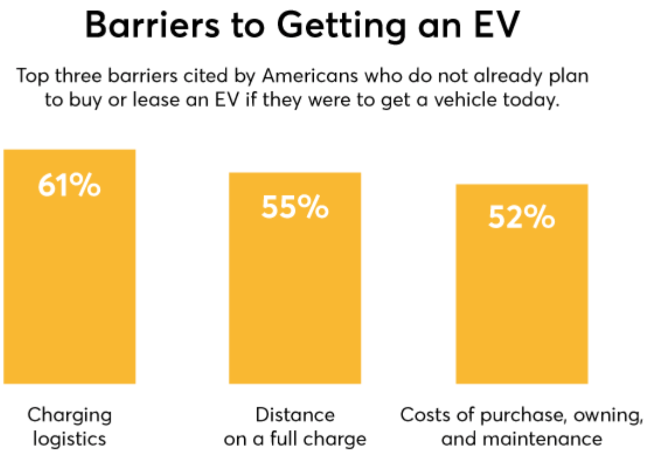
Source: IEA, 2022

- In 2019, 2.2 million EVs were sold, ~2.5% of global car sales.
- In 2020, the overall car market contracted but EV sales bucked the trend, rising to 3 million and representing 4.1% of global car sales.
- In 2021, EV sales more than doubled to 6.6 million, representing ~9% of the global market.
- In **Sept. 2022,** EV sales were **17% of the global market** (BEVs were 13%)

~7% in the U.S.

Charging 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**.
- Recent study shows **EV "discontinuance" related to dissatisfaction with the convenience of charging** and not having level 2 (240-volt) charging at home.



Source: Consumer Reports survey of 8,027 U.S. adults in early 2022

nature energy

Understanding discontinuance among California's electric vehicle owners

Scott Hardman & Gil Tal

https://doi.org/10.1038/s41560-021-00814-9

EV Charging a Priority for Federal Government

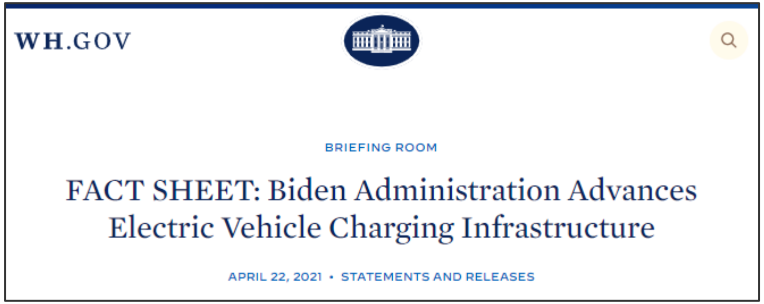
Ambitious goals to **grow domestic EV and EV charging markets** through 2030:

- 500,000 PEV chargers
- 50% of LDV sales as ZEV

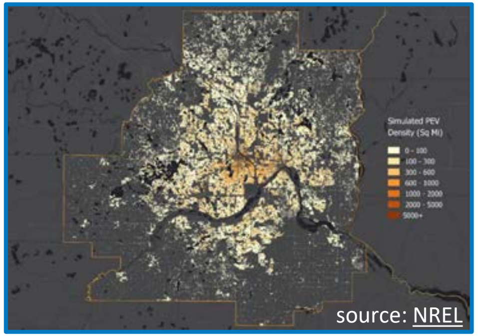
Backed by **new federal policies and support**:

- 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...

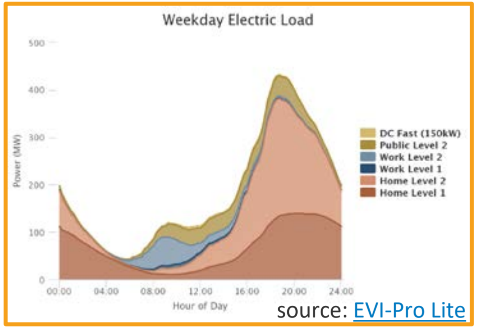


Preparing for EVs: not *if* but ***when***, ***where***, and ***how much?***



source: NREL

source: Wood et al.



source: EVI-Pro Lite

Where EVs are adopted

- Which regions, communities, households are likely to adopt EVs?
- What types of EVs will be adopted?
- How quickly will EVs be adopted?

How EVs are operated

- How do driving requirements vary by region or household?
- Where are EVs parked during the day?
- Do EV travel patterns differ from conventional vehicles?

How EVs are charged

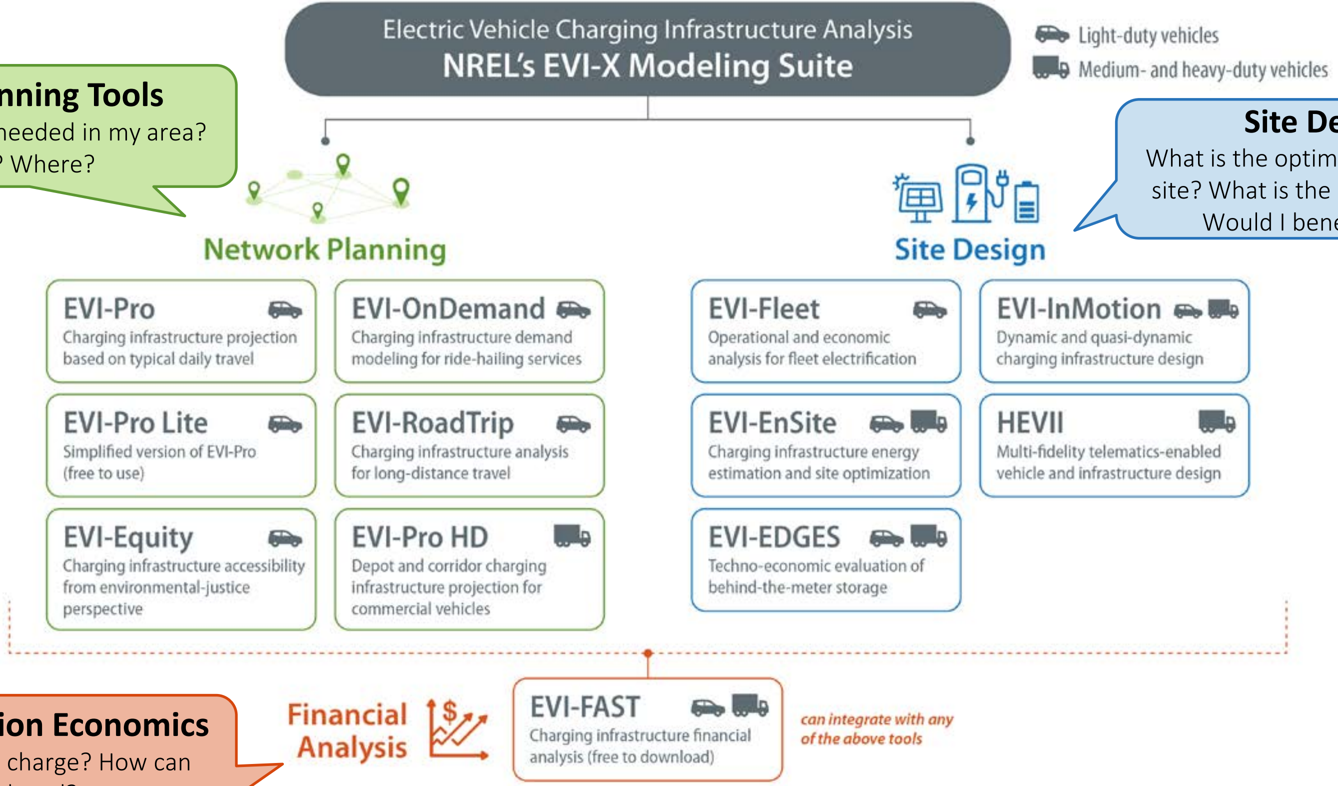
- Can EVs charge while at home, work, or in public?
- How do EV drivers prefer to charge, and will this change over time?
- Can EVs shift (in time) or modulate their loads?

EVI-X: Modeling Tools for Forward Looking Analysis

Network Planning Tools
How many ports are needed in my area? What kind? Where?

Site Design Tools
What is the optimal configuration for my site? What is the expected load profile? Would I benefit from storage?

Network & Station Economics
What does it cost to charge? How can this be reduced?

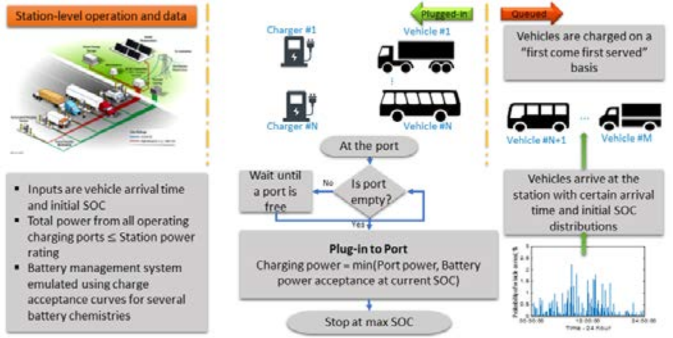


https://www.nrel.gov/transportation/evi-x.html

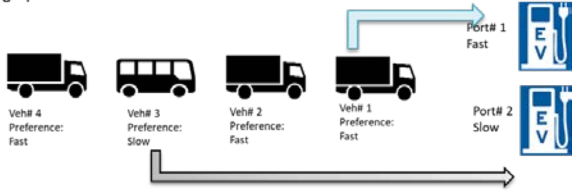
EVI-X: **Site Design**

[**EVI-EnSite**](https://www.nrel.gov/transportation/evi-ensite.html) – agent-based charging station modeling and analysis tool to investigate site operating requirements.

- **Charging Station design parameters**:
  - Station power capacity
  - Number of ports
  - Port power capacity
- **Answers questions such as:**
  - How should EV charging stations be designed?
  - How much queuing is expected at a proposed station?
  - What site-level control policies can reduce grid requirements while limiting inconvenience?
  - What is the average utilization of a station?
  - What is the total power demand of a station?



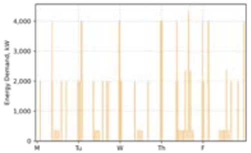
New queuing model: Allows vehicle to plug in when their preferred charger (slow or fast charger) is available



EVI-EnSite

EV Infrastructure: Energy Estimation & Site Optimization Tool

Example Station Load Profile



EVI-EnSite *simulates EV station operations, producing site load profiles and performance metrics like station peak and average power demand, energy delivered by port type, and vehicle queuing statistics.*

https://www.nrel.gov/transportation/evi-ensite.html

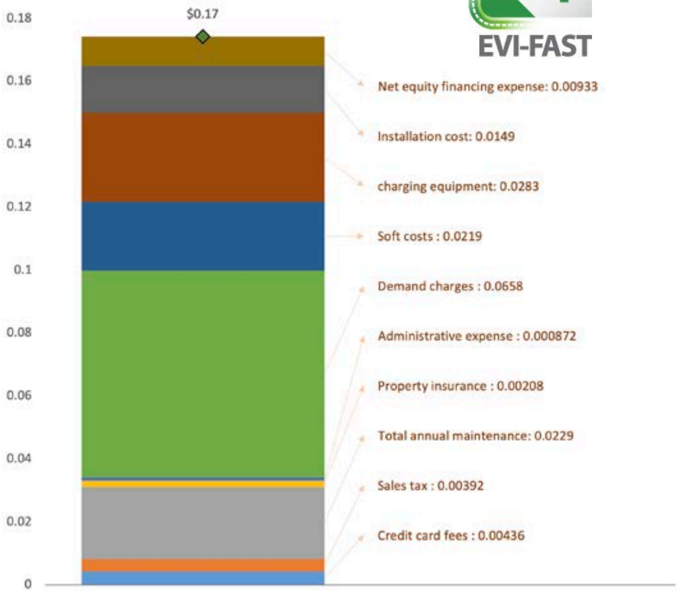
EVI-X: **Network/Station Economics**

EVI-FAST – EV station financial analysis tool

- **Publicly accessible** tool for in-depth financial scenario analysis of EV charging stations.
- **Highly configurable** – inputs include station design (power capacity), utilization, costs (equipment, installation, and operating), incentives, and financing assumptions.
- Calculates financial performance metrics including **investor payback period, net present value**, and the **levelized cost of charging** ($/kWh) for each station scenario.
- Used in multiple recent DOE analyses[1,2]

https://www.nrel.gov/transportation/evi-fast.html

Breakdown of Station LCOC ($/kWh)



***EVI-FAST** estimates the levelized cost of charging (i.e., the breakeven cost of charging inclusive of capital expenses (e.g., EVSE), operating costs (e.g., electricity purchases), and financing assumptions) for EV charging stations.*

[1] Borlaug et al., 2020, "Levelized Cost of Charging Electric Vehicles in the United States", *Joule*

[2] Bennett et al., 2022, "Estimating the Breakeven Cost of Delivered Electricity to Charge Class 8 Electric Tractors", NREL/TP

EVI-X: **Network Planning**

[EVI-Pro](https://www.nrel.gov/transportation/evi-pro.html) is a simulation model that:

- Models **typical daily charging demands** for EVs
- Designs **supply of infrastructure** to meet demand

Models EV driver charging behaviors for a given set of assumptions around EVSE access and charging preferences.

Originally developed through a collaboration with the California Energy Commission, EVI-Pro has been applied in multiple city-, state-, and national-level studies

EVI-Pro

https://www.nrel.gov/transportation/evi-pro.html

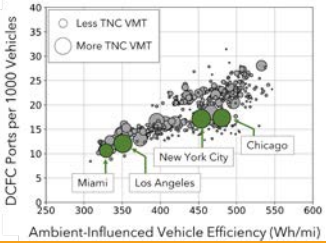
[EVI-RoadTrip](https://www.nrel.gov/transportation/evi-roadtrip.html) estimates EV charging demands along highway corridors for **long-distance travel** (road trips).

EVI-RoadTrip

https://www.nrel.gov/transportation/evi-roadtrip.html

EVI-OnDemand estimates DC fast charging infrastructure requirements for **ride-hail EVs** considering:

- Local weather/driving conditions
- Typical driver shift lengths
- Home charging access for ride-hail drivers



There is a need for **integrated systems modeling and analysis** to better assist public/private stakeholders in **preparing for the U.S. energy transition**…

“The 2030 National Charging Network” Study

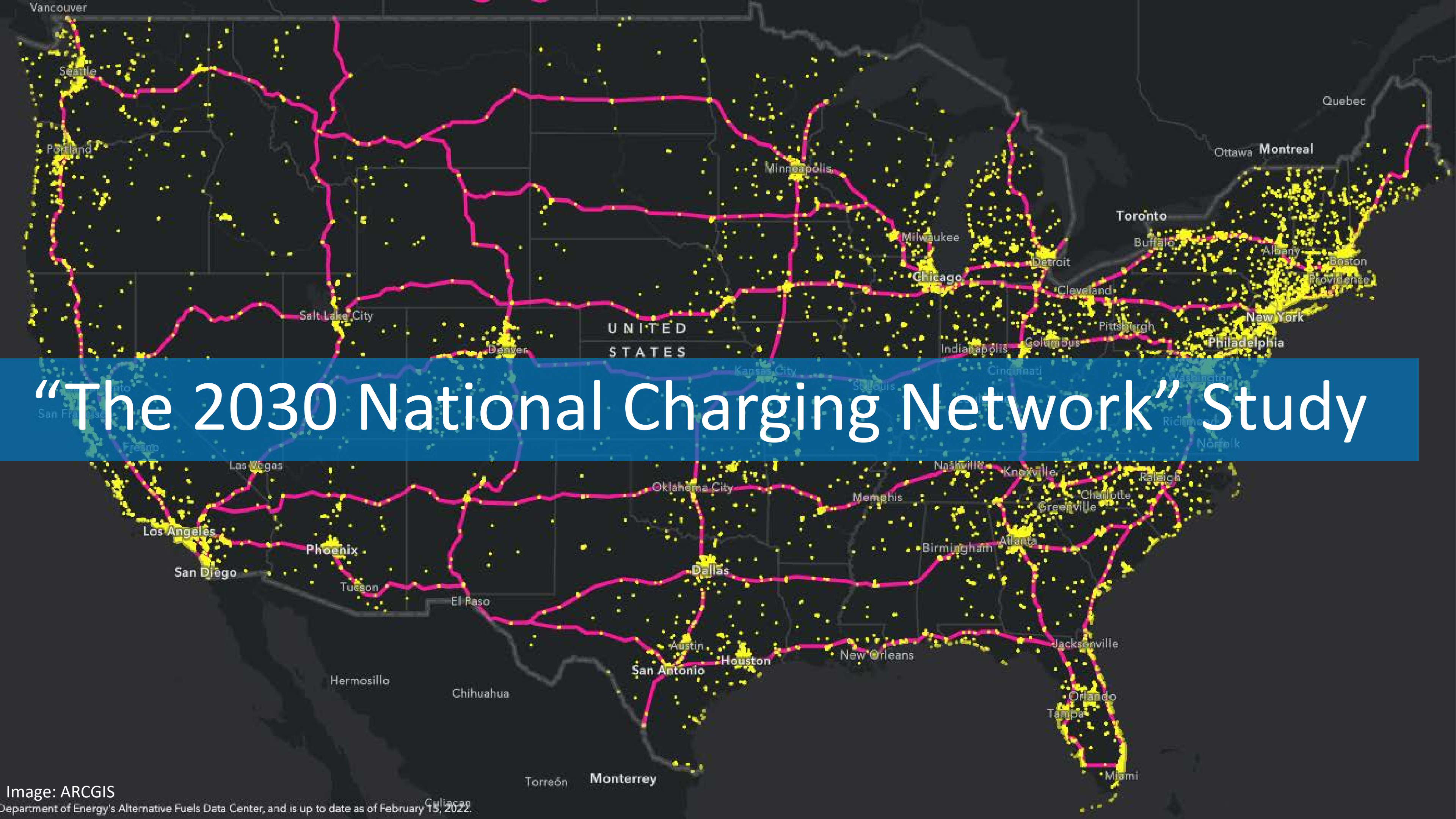


Image: ARCGIS

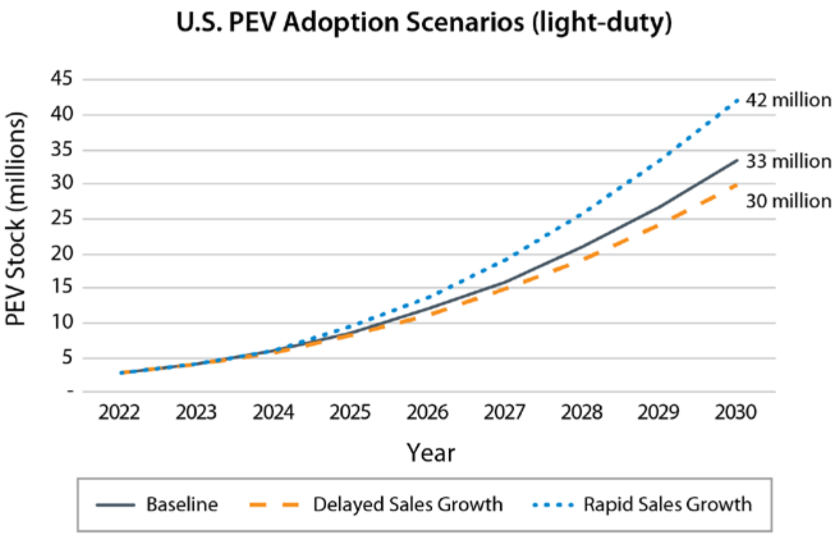
Department of Energy's Alternative Fuels Data Center, and is up to date as of February 15, 2022.

Study Objective

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

Primary Research Questions:

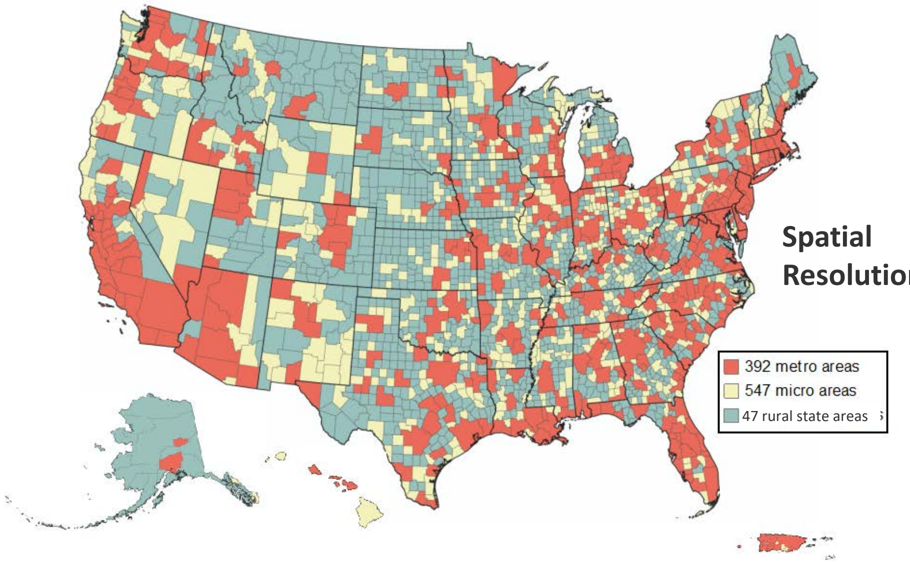
- What are the charging demands and how much charging infrastructure is needed to support **high levels of EV adoption by 2030**?
- Which types of EVSE should be prioritized and where?
- What will it cost to build out the EVSE network over time?



__TEMPO-modeled__ national light-duty PEV adoption trajectories

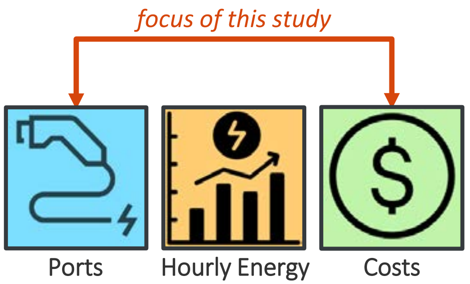
Scope of Modeling

Outputs:	EVSE port counts and costs
Vehicle Segment:	Personally-owned light-duty vehicles
Timeframe:	2022 - 2030
Spatial Resolution:	986 CBSAs/rural-state areas (see below)
EVSE Types:	(see EVSE Taxonomy table)



Spatial Resolution

Outputs:



by...

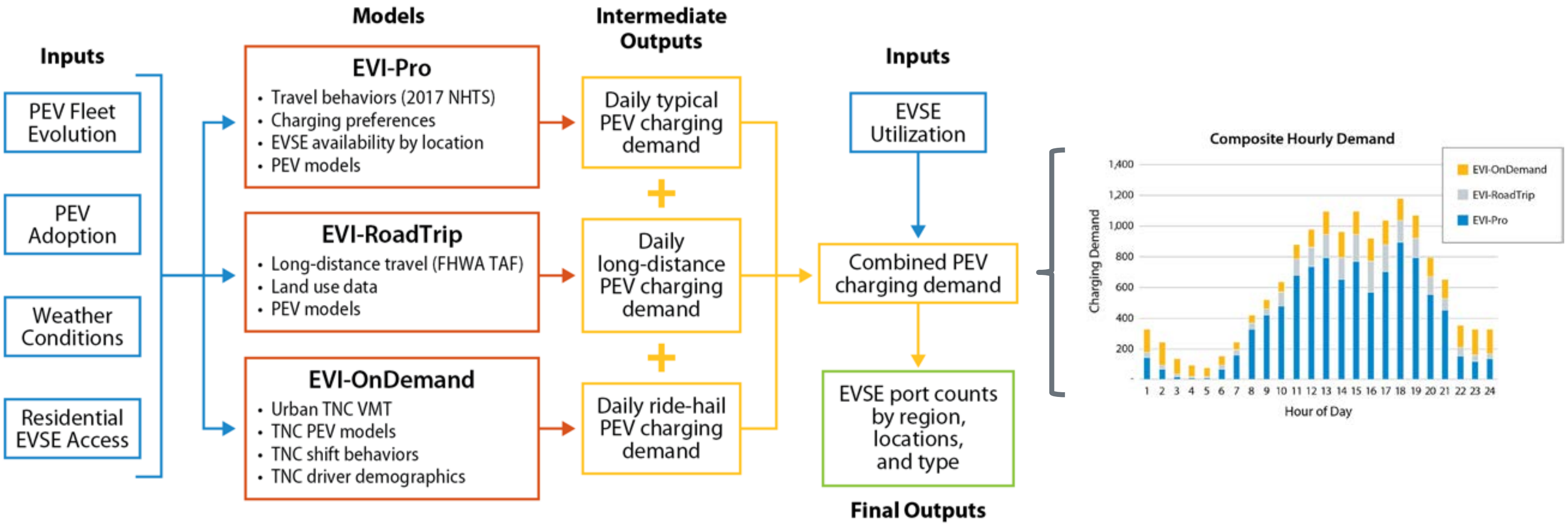
EVSE Taxonomy

Access Type	Public	Private
Location Type	Home: SFH Home: MFH Neighborhood Workplace Office Retail	Recreational Healthcare School Community Center Transit Hub
EVSE Type	Level 1 Level 2 DC 50 kW	DC 150 kW DC 250 kW DC 350+ kW

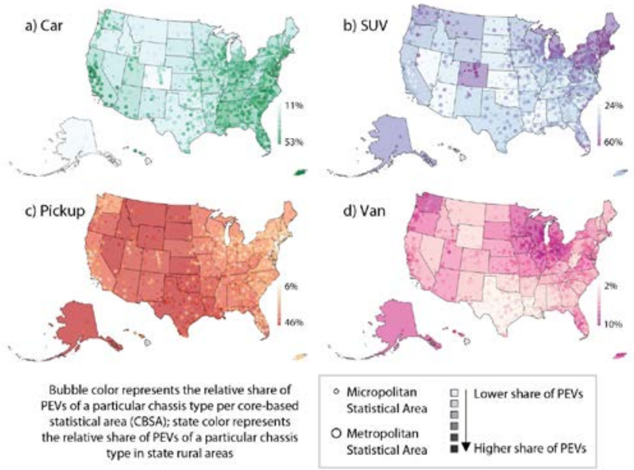
Modeling Approach

National modeling framework standardizes inputs and combines outputs for each of the light-duty EVI- demand models.

Captures regional differences in EV charging demands and port requirements due to differences in travel patterns, residential charging access, PEV adoption rates, vehicle type preferences, and weather conditions.

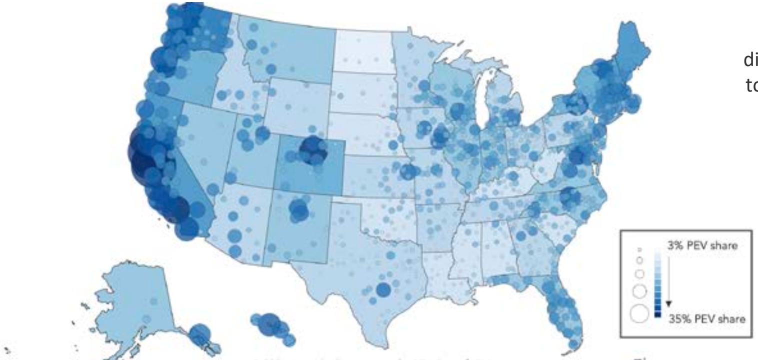


Baseline Assumptions



Bubble color represents the relative share of PEVs of a particular chassis type per core-based statistical area (CBSA); state color represents the relative share of PEVs of a particular chassis type in state rural areas

2030 PEV chassis mix = new LDVs (MY2019-22)



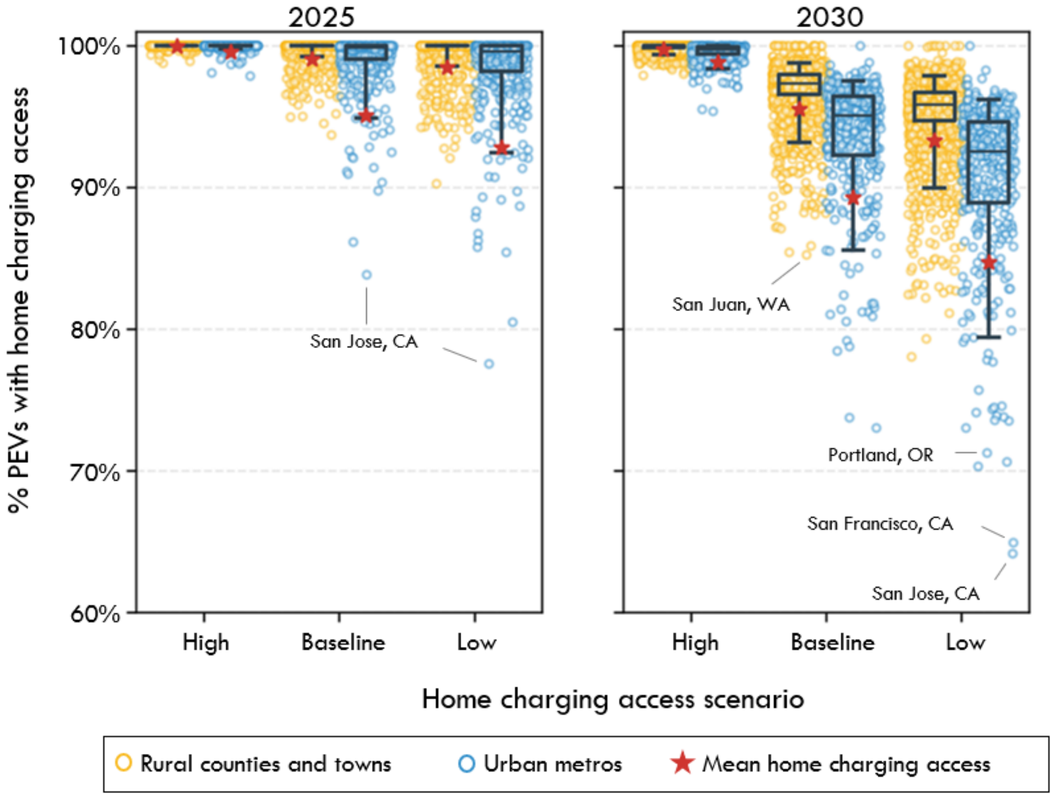
Bubble size and color represent the PEV share of LDVs per core-based statistical area (CBSA); State color represents the PEV share of LDVs in state rural areas

2030 PEV spatial distribution skewed toward 2022 PEV & HEV distribution

Demand-Side Assumptions: Baseline Scenario

Modeling Parameter	2030 Nominal Assumption
PEV fleet size (LDV only)	33 million (2.7 million registered as of 2022)
PEV powertrain shares	BEV = 90% (2022: 72%) PHEV = 10% (2022: 28%)
PEV body type distribution	Sedan = 24% (2022: 58%) C/SUV = 56% (2022: 40%) Pickup = 17% (2022: 0%) Van = 3% (2022: 2%)
Average PEV electric range (model year 2030)	BEV = 300 miles PHEV = 45 miles
BEV minimum DC charge time (model year 2030; 20%–80% state of charge [SOC])	20 minutes [a]
Maximum DC power rating (per port)	350+ kW
Geographical distribution	Scaled proportional to existing PEV and gasoline-hybrid registrations with a ceiling of 35% of LDVs on the road in 2030 as PEVs in high adoption areas and a floor of 3% in low adoption areas
PEVs with reliable access to residential charging	90%
Weather conditions	Typical ambient conditions are used for each simulated region, impacting electric range accordingly
Driving behavior	EVI-Pro: Consistent with Federal Highway Administration (FHWA) 2017 National Household Travel Survey (NHTS) EVI-RoadTrip: Directly applies FHWA Traveler Analysis Framework (TAF) EVI-On Demand: Consistent with Balding et al. (2019)
Charging behavior	All models attempt to maximize use of home charging (when available) and utilize charging away from home only as necessary. When fast charging is necessary, BEVs prefer the fastest option compatible with their vehicle, up to 350+ kW.

Home Charging Access



https://www.nrel.gov/docs/fy22osti/81065.pdf

Home Access Scenarios:

Low: Scenario 2 – only PEV drivers with existing electrical access where the vehicle is parked can charge at home (Ge et al.)

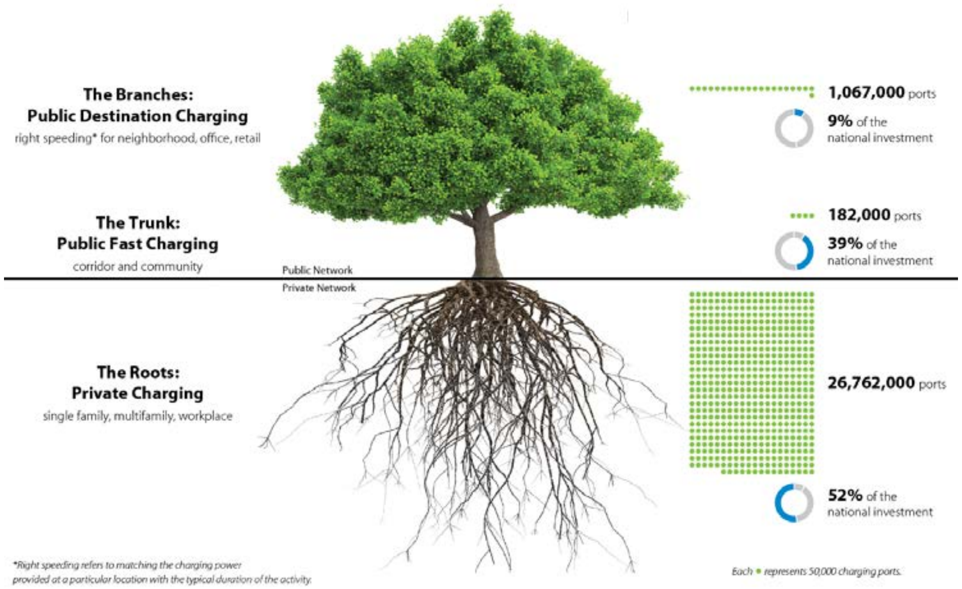
Baseline: 50% Scenario 2, 50% Scenario 3 (Ge et al.)

High: Scenario 5 – Assumes all PEV drivers who can park their vehicle in a location where electrical access can be installed can charge at home (Ge et al.)

Key Findings (1/5)

Convenient and affordable charging at/near home is core to the ecosystem but must be complemented by reliable public charging:

- **26.8 million Level 1 and Level 2 charging ports** in **privately accessible locations** [96% of ports, 52% of investment]
  (single-family homes, multifamily properties, and restricted access workplaces)
- **1 million Level 2 charging ports** in **publicly accessible locations** [4% of ports, 9% of investment]
  (near high-density neighborhoods, public access workplaces, and other long-dwell locations)
- **182,000 fast charging ports** in **publicly accessible locations** [<1% of ports, 39% of investment]
  (grocery stores, convenience stores, and other short-dwell locations)



Port (thousands)

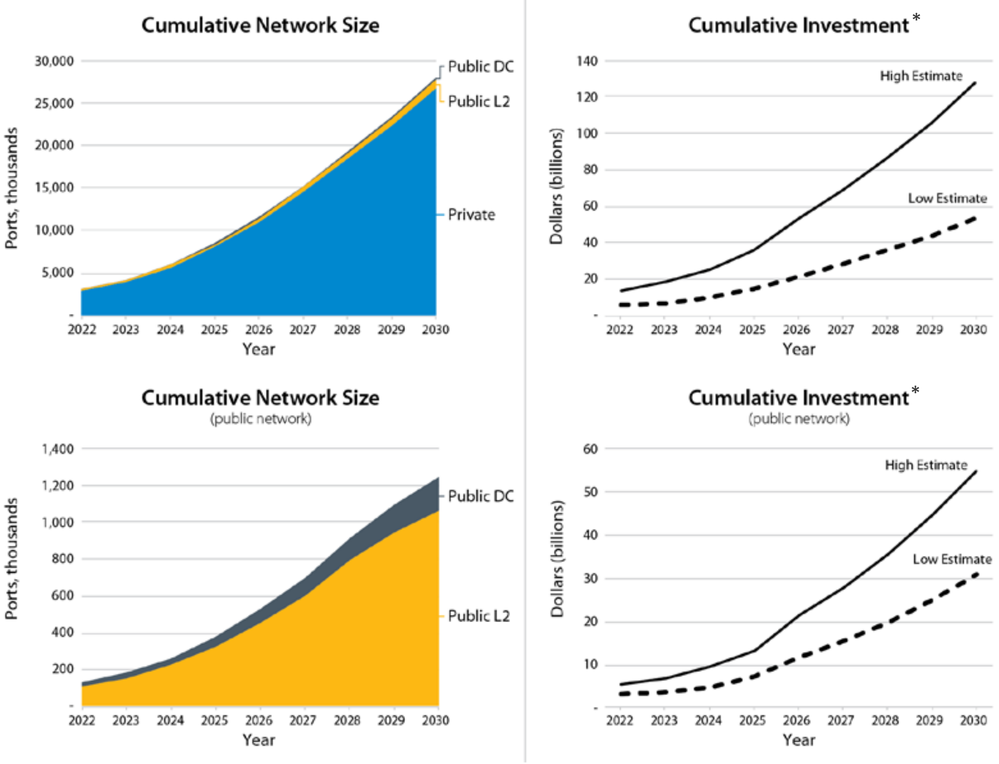
Public		1,248
	Level 2	**1,067**
	Neighborhood	305
	Office	206
	Retail	178
	Healthcare	100
	Recreational	84
	Transport Hub	75
	School	62
	Com. Center	56
	DC Fast	**182**
	DC150	63
	DC250	55
	DC350+	64
Private		26,762
	Level 1	**7,024**
	Single Family	7,024
	Level 2	**19,738**
	Single Family	18,686
	Multifamily	568
	Workplace	485

Key Findings (2/5)

Continued growth and investment in the EV charging network will be required to meet 2030 sales targets.

- High uncertainty around cost requirements due to significant site-level variability in EVSE equipment and installation costs.
- Significant public and private investments in EV charging have already been made and will need to continue through the end of the decade.

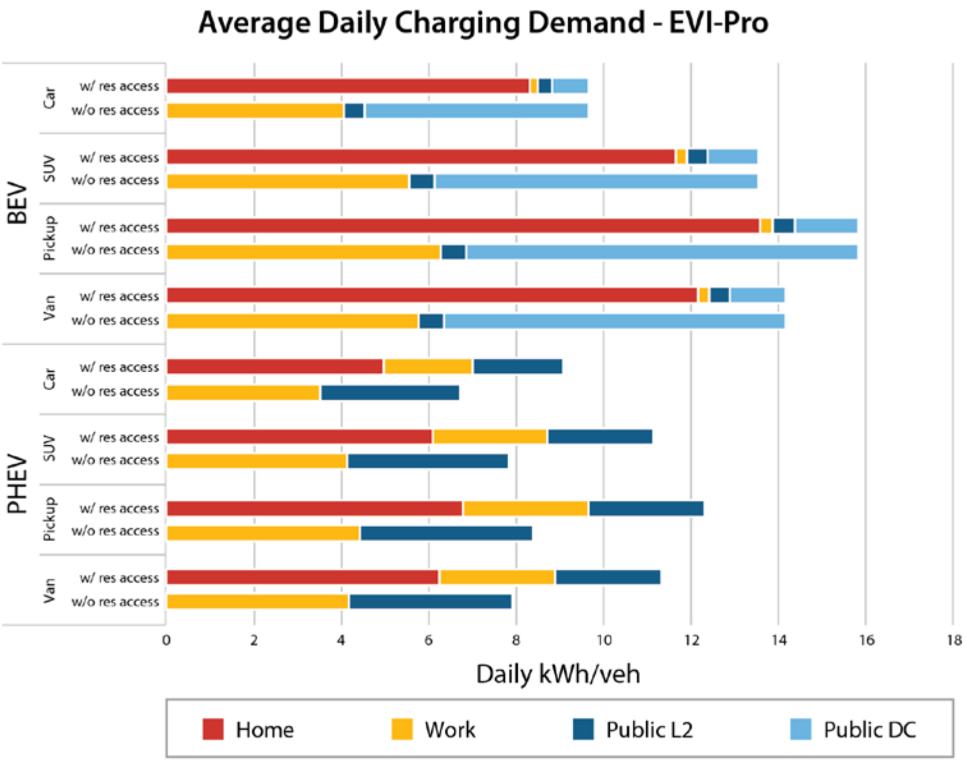
*Cumulative Investment is defined as capital expenses for equipment and installation necessary to support EV charging. Costs of grid upgrades and distributed energy resources have been excluded from these estimates; however, these can be significant and will ultimately be critical for building out the national charging network.



Key Findings (3/5)

Charging demands and infrastructure requirements vary by vehicle type and for those with/without home charging.

- Larger vehicles = higher energy demands
- PHEVs have lower electricity demands (smaller batteries) than BEVs and may rely more on public L2 charging*
- Without home charging, drivers rely more on workplace and public charging networks for daily travels.

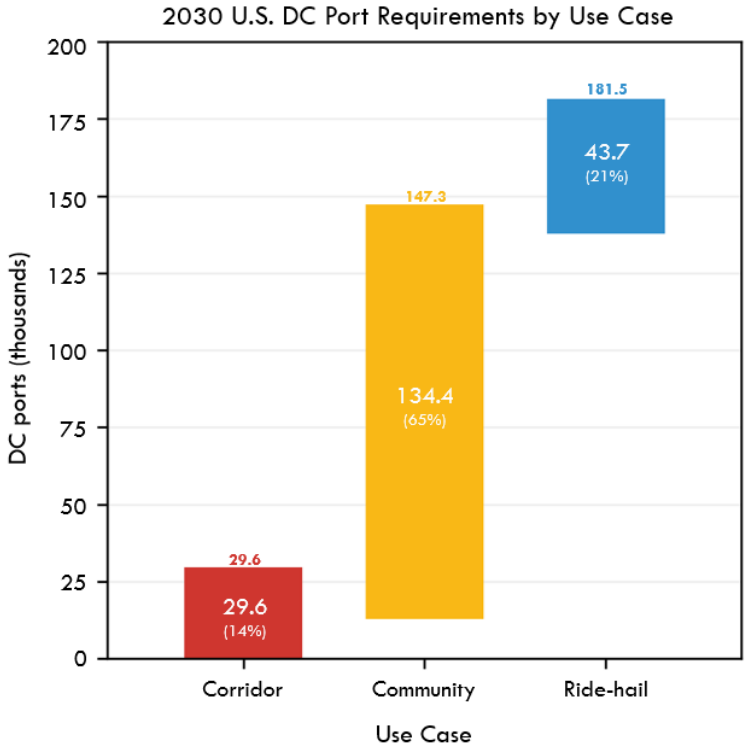


*this study assumes that PHEVs are incapable of DC fast charging

Key Findings (4/5)

The public DC fast charging network will serve multiple use cases:

- The majority (**65%**) of demand is in support of **daily travel (community charging)**, particularly for those without reliable home or workplace charging.
- **21%** of demand from **ride-hail** EVs, a disproportionate share compared to other LDVs.
- **14%** of demand from **long-distance travel (corridor charging)**, though these stations are critical for providing comprehensive national coverage (reducing ”range anxiety”).

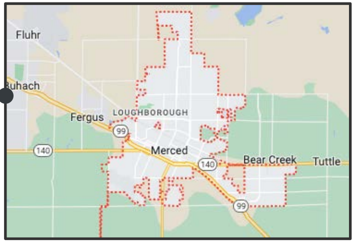


Key Findings (5/5)

The composition of the public charging network will vary regionally.

- Densely populated areas will require significant investments to support those in multi-family homes without a home charger and for ride-hailing electrification.
- More rural areas will require fast charging along highways to support long-distance travel for those passing through (see below).

CBSA	PEVs	DC Ports	DC Ports per 1,000 PEVs
Merced, CA	26,000	349	13.2
Redding, CA	24,000	236	9.7
Bakersfield, CA	83,000	639	7.7
El Paso, TX	50,000	365	7.3
Lafayette, LA	24,000	173	7.2
St. George, UT	27,000	191	7.1
Gainesville, FL	29,000	202	6.9
Duluth, MN	24,000	161	6.8
Green Bay, WI	27,000	177	6.6
Youngstown-Warren-Boardman, OH-PA	31,000	202	6.5
Top 200 CBSAs	**27,621,000**	**110,000**	**4.0**



Google Maps

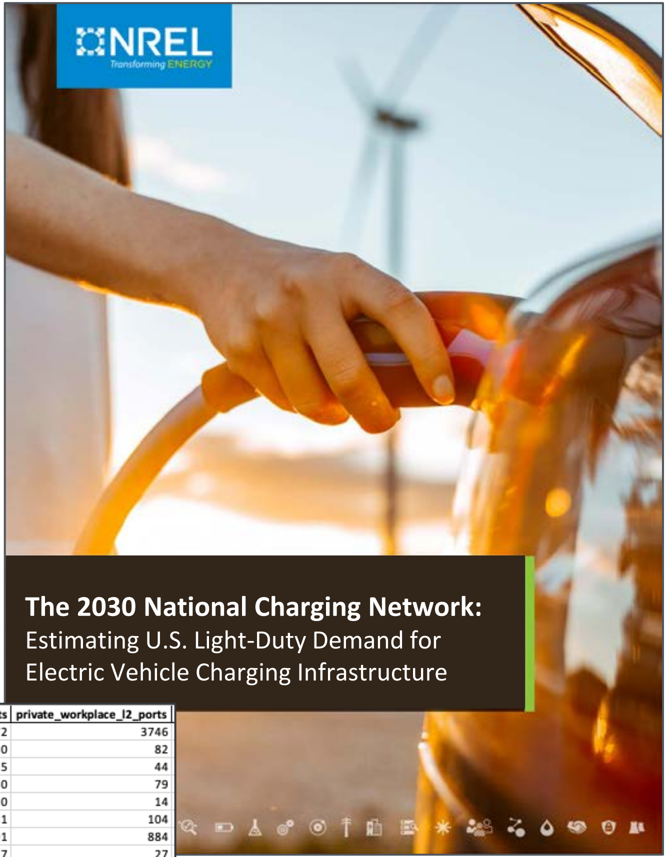
Higher share of charging demand from road-trippers passing through the region

Report Available Now!

https://www.nrel.gov/docs/fy23osti/85654.pdf

Also includes:

- Detailed results and discussion for baseline and 11 sensitivity scenarios.
- **Downloadable** data files containing detailed results (PEVs and port counts) at the state- or CBSA-level for all scenarios (2025 and 2030).



Example data file (2030 baseline – Alabama)

region_type	region_id	region_name	year	pevs	bevs	phevs	private_sfh_l2_ports	private_sfh_l1_ports	private_mud_l2_ports	private_workplace_l2_ports
State	1	Alabama	2030	312143	279339	32804	193417	72854	872	3746
Micropolitan Statistical Area	10700	Albertville, AL Micropolitan Statistical Area	2030	6232	5576	656	3858	1454	0	82
Micropolitan Statistical Area	10760	Alexander City, AL Micropolitan Statistical Area	2030	3390	3028	362	2120	800	5	44
Metropolitan Statistical Area	11500	Anniston-Oxford, AL Metropolitan Statistical Area	2030	6716	6000	716	4204	1586	0	79
Micropolitan Statistical Area	12120	Atmore, AL Micropolitan Statistical Area	2030	1591	1427	164	1011	380	0	14
Metropolitan Statistical Area	12220	Auburn-Opelika, AL Metropolitan Statistical Area	2030	10726	9588	1138	6692	2523	31	104
Metropolitan Statistical Area	13820	Birmingham-Hoover, AL Metropolitan Statistical Area	2030	70337	62978	7359	43589	16404	391	884
Metropolitan Statistical Area	17980	Columbus, GA-AL Metropolitan Statistical Area	2030	2892	2591	301	1779	669	7	27
Micropolitan Statistical Area	18980	Cullman, AL Micropolitan Statistical Area	2030	5618	5039	579	3523	1325	0	69
Metropolitan Statistical Area	19300	Daphne-Fairhope-Foley, AL Metropolitan Statistical Area	2030	20243	18065	2178	12258	4625	150	237
Metropolitan Statistical Area	19460	Decatur, AL Metropolitan Statistical Area	2030	9333	8334	999	5824	2200	16	110
Metropolitan Statistical Area	20020	Dothan, AL Metropolitan Statistical Area	2030	9394	8395	999	5848	2207	6	117
Micropolitan Statistical Area	21460	Enterprise, AL Micropolitan Statistical Area	2030	3698	3308	390	2309	870	0	44
Micropolitan Statistical Area	21640	Eufaula, AL-GA Micropolitan Statistical Area	2030	1165	1038	127	735	278	2	9
Metropolitan Statistical Area	22520	Florence-Muscle Shoals, AL Metropolitan Statistical Area	2030	8935	7992	943	5629	2122	3	97
Micropolitan Statistical Area	22840	Fort Payne, AL Micropolitan Statistical Area	2030	4405	3945	460	2799	1053	0	50

• • •

EVI-Pro Lite

Public Planning Tools Promote Sound Investments

Sophisticated (yet simple to use) public planning tools are valuable for a variety of stakeholders, leading to:

- **Improved understanding** of current and future landscapes.
- **Effective implementation** of costly programs and initiatives.

EVI-Pro Lite: **Overview**

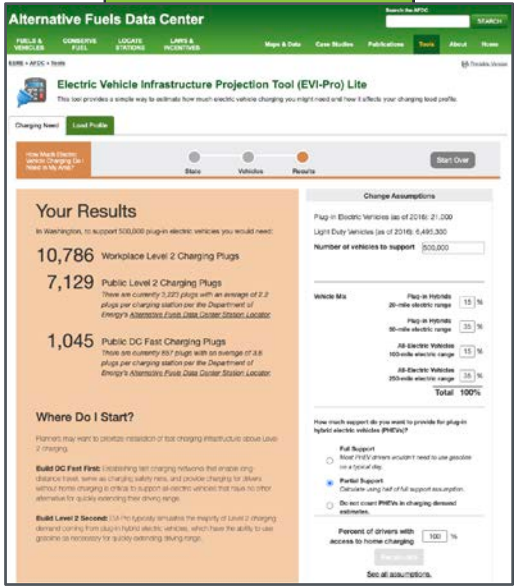
EVI-Pro Lite Objective:
Make analytic capabilities of EVI-Pro model accessible to broad group of stakeholders for EVSE investment decisions.

Approach:
Develop a simplified, web-based interface for EVI-Pro that gives users access to a limited number of critical input variables.

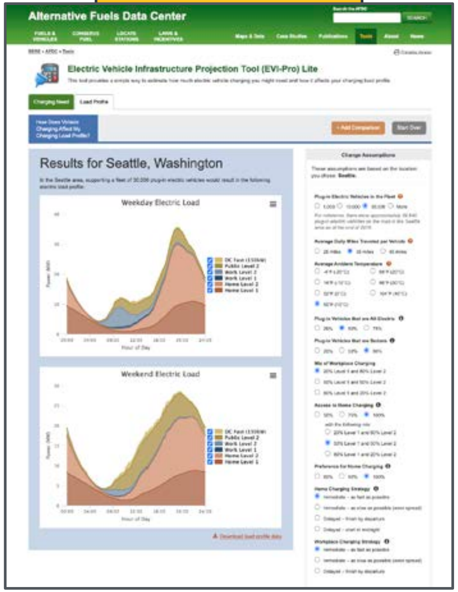
Capabilities: Recent 2023 update

- **"Charging Need"** tab: estimates EVSE port requirements for a region.
- **"Load Profile"** tab: estimates EV charging load profile for a region.

Charging Need Tab



Load Profile Tab

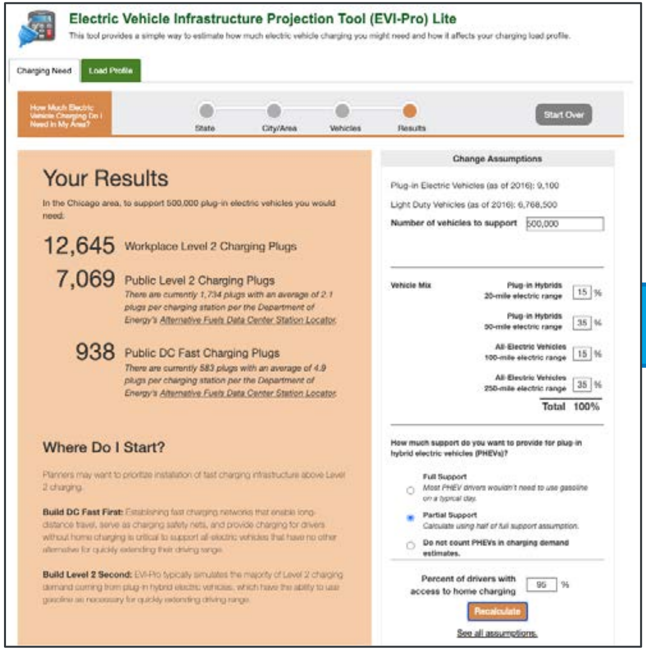


"Charging Need" tab (left) estimates EVSE port requirements while "Load Profile" tab (right) estimates EV load profiles

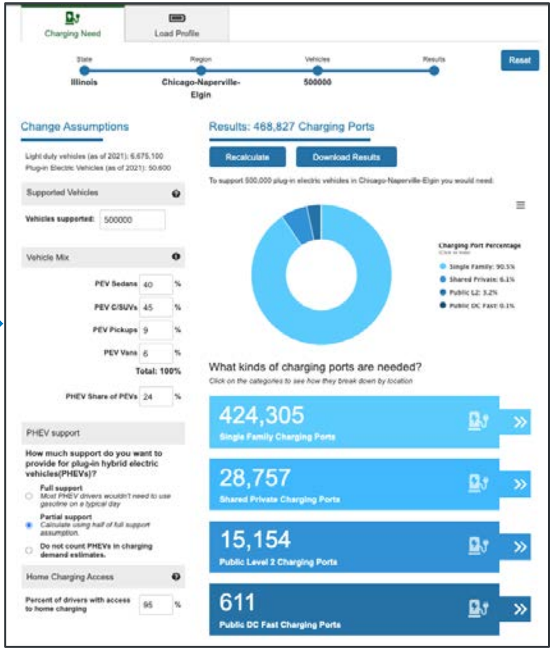
https://www.afdc.energy.gov/evi-pro-lite

EVI-Pro Lite: “Charging Need” Update

“Charging Need” 1.0



“Charging Need” 2.0

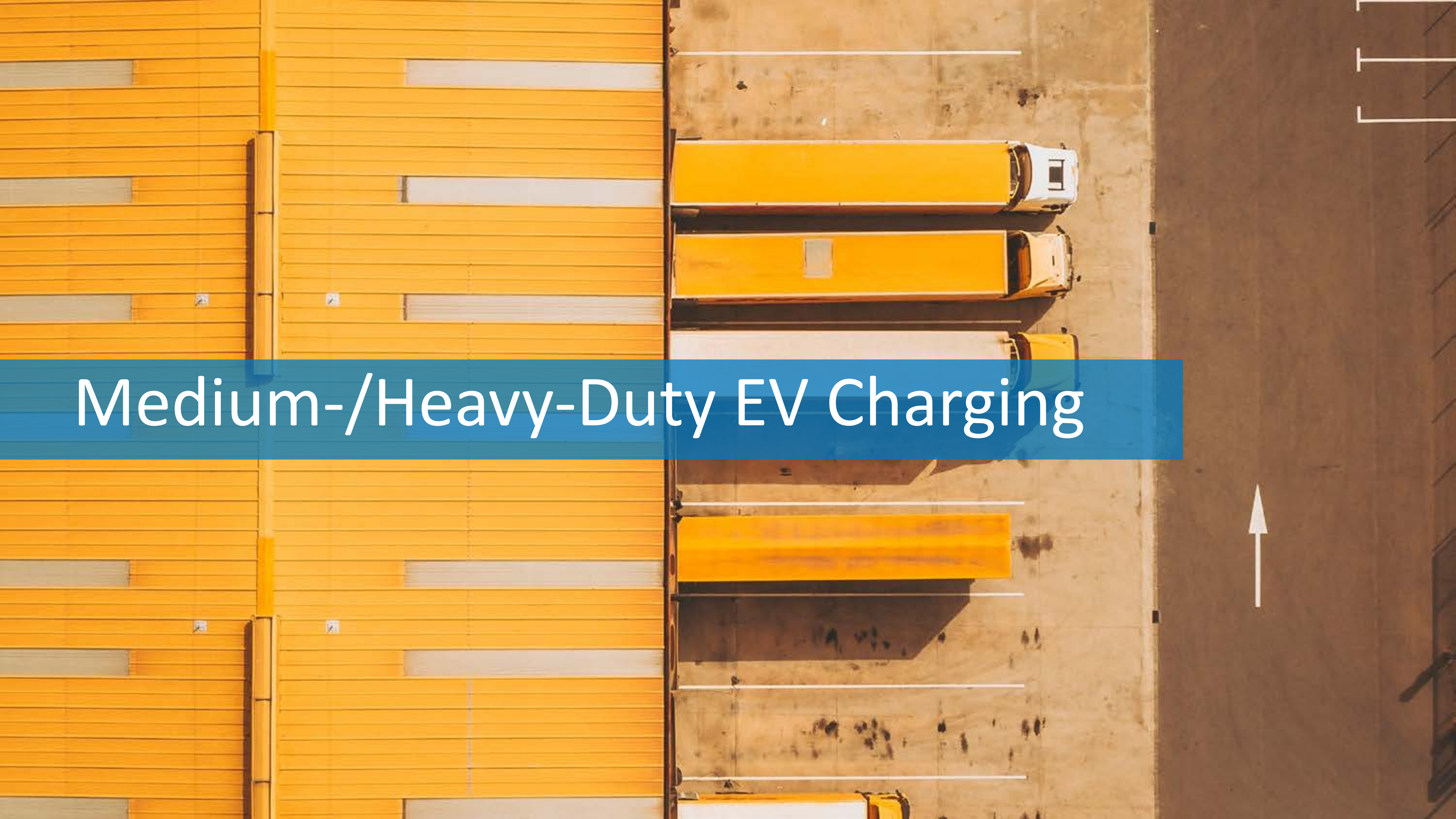


https://www.afdc.energy.gov/evi-pro-lite

Enhancements:

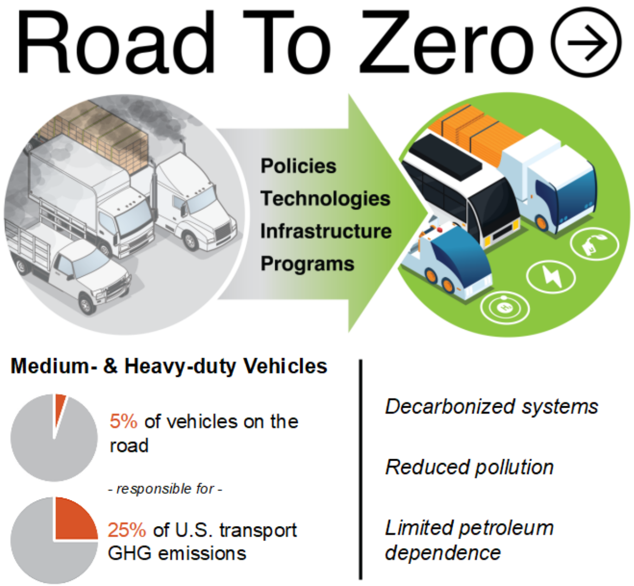
- *Previous EV fleet size and home charging access* ***input constraints removed****.*
- *Incorporates* ***region-specific travel behaviors*** *(aligned with 50x30 approach).*
- ***Improved EV chassis type representation*** *including sedans, C/SUVs, pickups, & vans.*
- ***More detailed outputs*** *including port requirements by EVSE power level and detailed location types (e.g., retail, healthcare facility, etc.)*
- ***Refreshed user interface***

Medium-/Heavy-Duty EV Charging



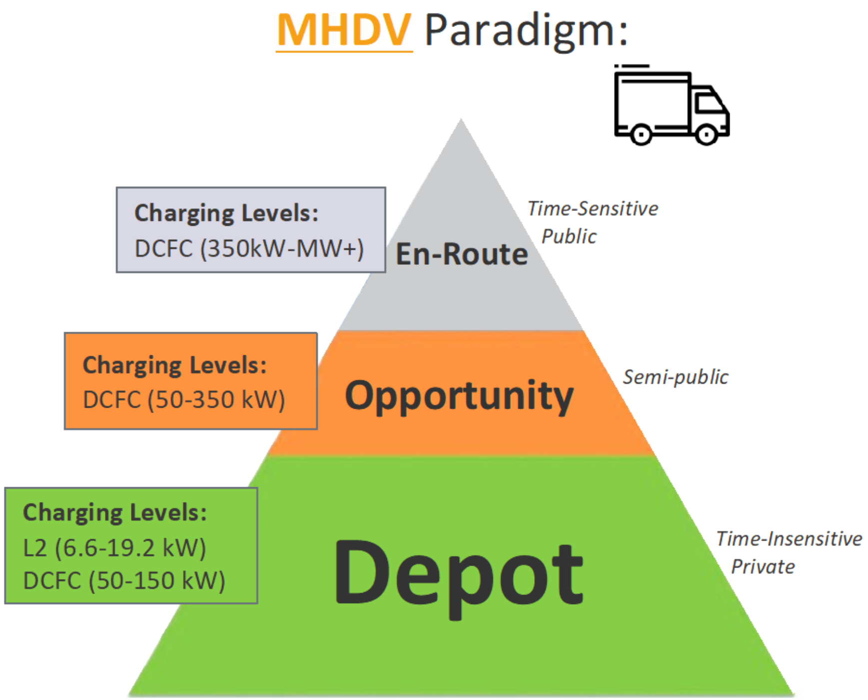
Beyond Cars: **M/HD EVs are Becoming a Reality**

- **Medium and heavy-duty vehicles (M/HDVs)** are the **2nd largest source of transport-related CO_2 emissions in the U.S.** (~25% of total).
- M/HDVs are also a **major source of local air pollutants** that negatively impact urban air quality and human health.
- **Battery electric vehicles (EVs) offer a promising decarbonization pathway for MHDVs** as battery technologies continue to improve and costs decline.
- **Certain M/HDV applications could electrify sooner than LDVs**, since:
  - Most M/HDVs are driven more than LDVs & EVs have lower operating costs
  - Fleet decisions are driven by economics (total cost of ownership)



Source: https://doi.org/10.1016/j.isci.2023.106751

M/HDV Charging Paradigm



Source: https://doi.org/10.1016/j.isci.2023.106751

Charging M/HD EVs involves **more options** than traditional refueling paradigms.

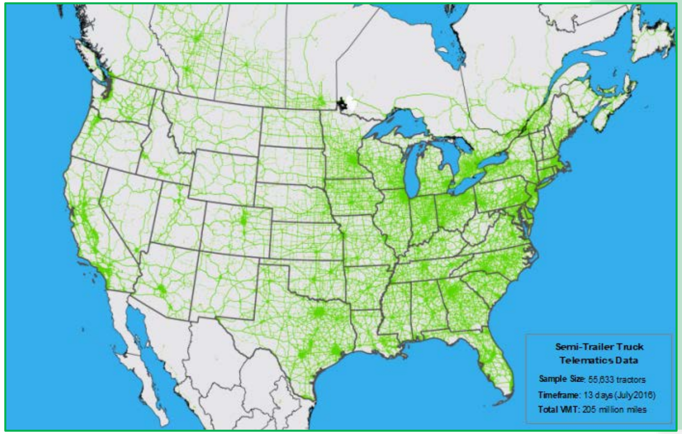
- **Depot charging** can cover a significant portion of total energy demands for return-to-base operations.
- **Opportunity charging** (e.g., while loading/unload or on break) could maximize operational efficiency.
- **Public en-route charging** will be needed as a "safety net" and for long-haul operations.

Heavy Truck Charging Depends on Multiple Factors

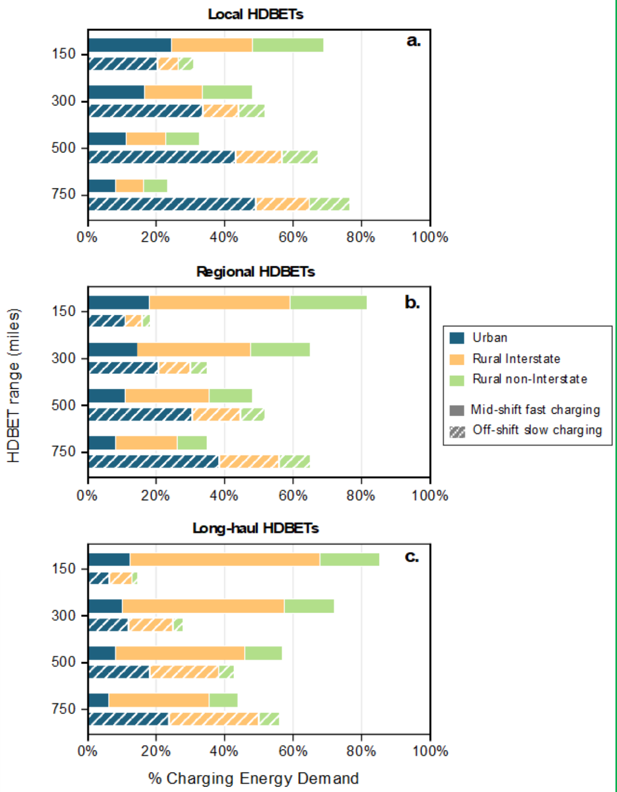
Findings:

- **kW-level off-shift charging** (≤350 kW) can provide significant share of total energy demands (even for long-haul).
- **MW-level mid-shift charging** crucial for long-haul and some regional/local trucks (assuming no change to existing operations)

Large-scale class 8 truck operating data



Insights on potential future class 8 BEV charging requirements



Source: https://doi.org/10.1016/j.rset.2022.100038

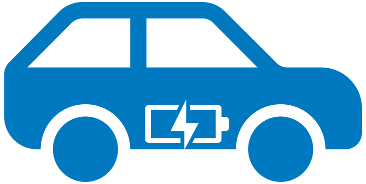
Expectations: LDV vs. M/HDV Charging

More vehicles with **lower electricity demands**

Charging is **geographically distributed**

Power level: several kW to **hundreds of kW per vehicle**

Spend **95% of the time parked** (opportunity for managed charging)



LDVs

VS

M/HDVs

Fewer vehicles with **higher electricity demands**

Charging is more **geographically concentrated**

Power level: tens of kW to **1+ MW per vehicle**

Spend **less time parked**, but **more predictable operations** could enable managed charging

Conclusions

Conclusions

- Ambitious goals to **grow domestic EV and EV charging markets** through 2030:
  - 500,000 PEV chargers
  - 50% of LDV sales as ZEV
- **EV charging infrastructure requirements are hard to predict over time**; challenging to plan for...
- Sophisticated (yet simple to understand) public planning studies and tools are valuable for stakeholders, leading to:
  - **Improved understanding** of current and future landscapes.
  - **Effective implementation** of costly programs and initiatives.
- **NREL can help!** NREL has published many studies and has the tools/capabilities to assist with decision making around EV charging loads and infrastructure demands:
  - **NREL Transportation Research**: https://www.nrel.gov/transportation/
  - **EVI-X**: https://www.nrel.gov/transportation/evi-x.html
  - **The 2030 National Charging Network study**: https://www.nrel.gov/docs/fy23osti/85654.pdf
  - **EVI-Pro Lite**: https://afdc.energy.gov/evi-pro-lite

Thank You!

www.nrel.gov

brennan.borlaug@nrel.gov

NREL/PR-5400-87021

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NREL

Transforming ENERGY

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Wood et al., 2023, "The 2030 National Charging Network: Estimating U.S. Light-Duty Demand for Electric Vehicle Infrastructure", NREL/TP-5400-85654. https://www.nrel.gov/docs/fy23osti/85654.pdf.

Supplemental: EV Managed Charging

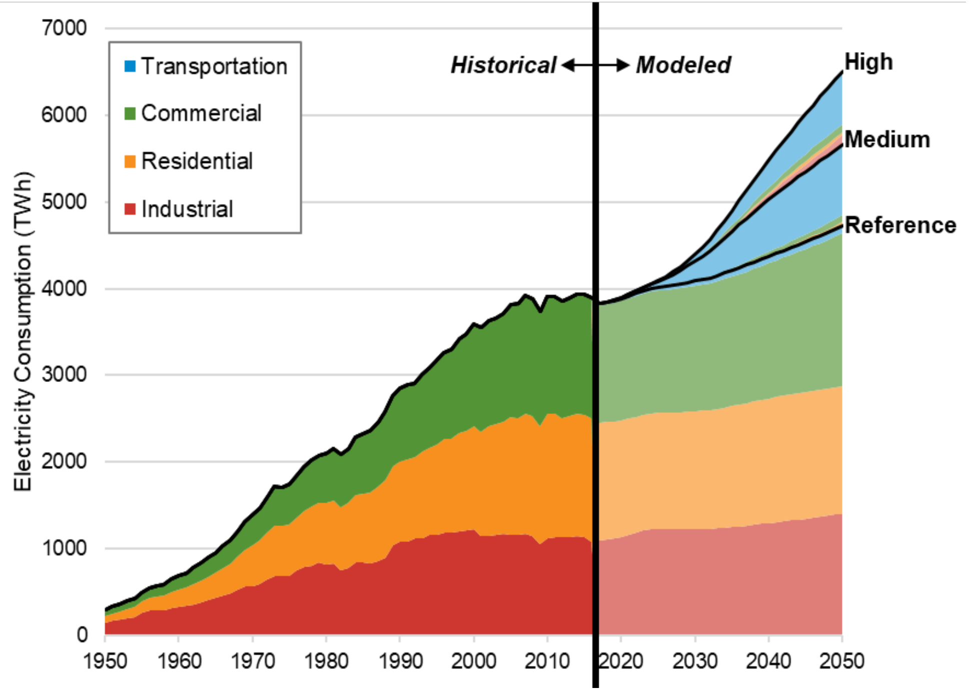
Large-Scale Economy-Wide Electrification

Growing EV adoption will **increase electricity demands**, requiring investments in generation, transmission, and distribution systems.

EFS High scenario, 2050:

- Total electricity demand increases ~50% from 2018 to 2050.
- **Transportation share of electricity use increases from 0.2% in 2018 to 23% in 2050** (1,424 TWh electricity consumption increase).

Electrify Everything!

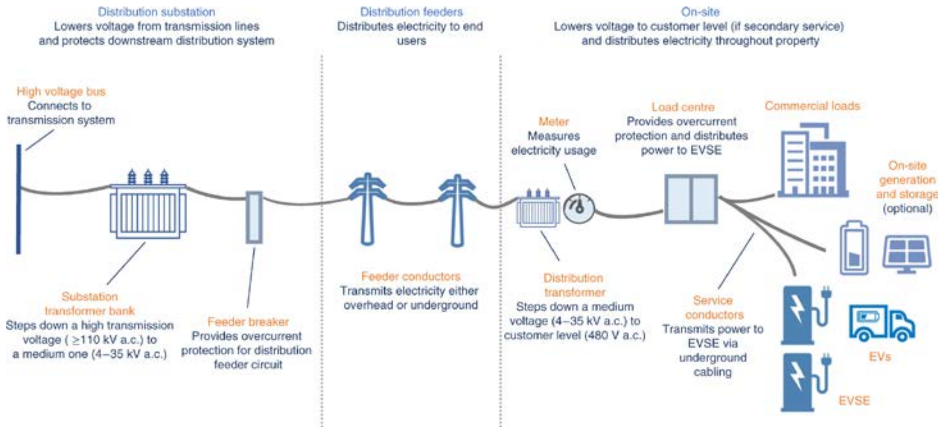


Source: NREL Electrification Futures Study
https://www.nrel.gov/analysis/electrification-futures.html

Potential Supply-Side Challenge: **EV-Grid Integration**

- **Grid capacity** plays a key role in determining optimal locations for EVSE deployments.
- The entire system of distribution equipment must be capable of supporting the **peak load demand** for all downstream loads.
- **High-power EVSE** for fast charging of LDVs and depot charging of M/HDVs typically require large interconnections.
- Larger interconnections to the distribution grid will likely require the installation of upgraded distribution equipment or the use of **peak demand mitigation** tactics.

Typical Electric Distribution System



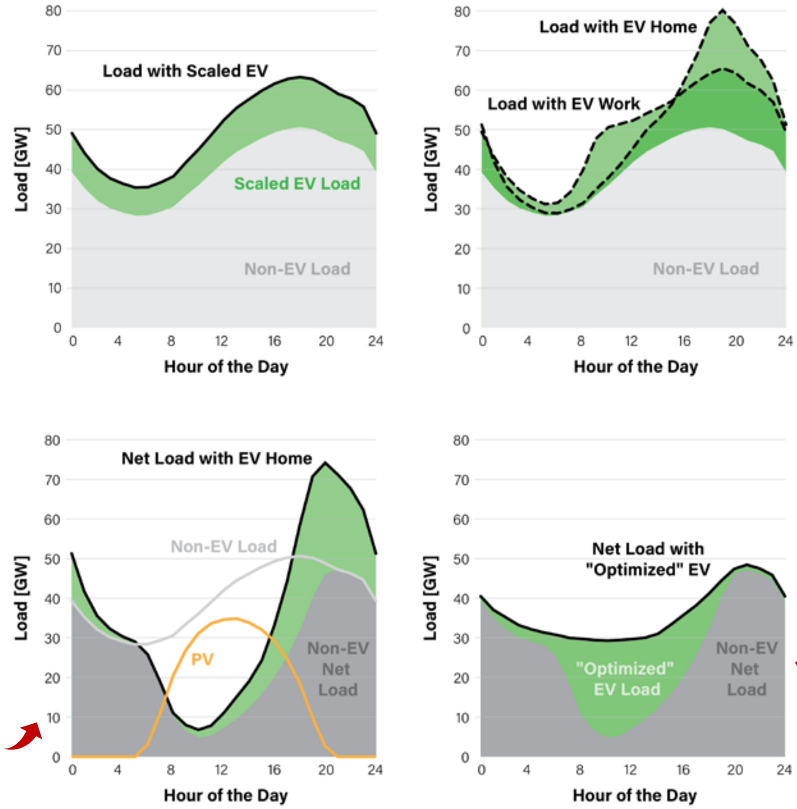
source: https://doi.org/10.1038/s41560-021000855-0

EVSE: electric vehicle supply equipment

Critical for Grid Integration: *When* & *Where* EVs Charge

a) ASSUMPTION:
EV charging is often assumed to simply scale up electricity demand.

b) COMPLEXITY:
Future EV charging could change the shape of demand, depending on when and where charging occurs.



c) INTEGRATION:
EV charging can impact power system planning and operations, particularly with high shares of variable renewable energy.

Unmanaged EV charging could **worsen the "duck" curve**

d) FLEXIBILITY:
Optimizing EV charging timing and location could add flexibility to help balance generation and demand.

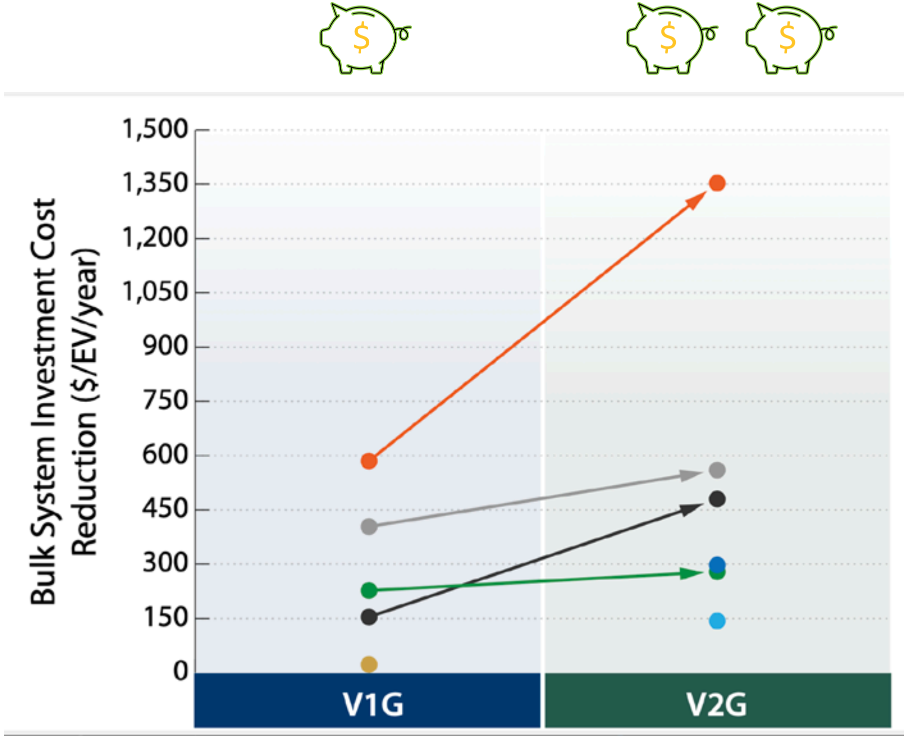
With the right incentives and infrastructure, **managed EV charging** could **flatten the "duck" curve** and increase renewables penetration

New class of models needed to assess the integration of EVs onto power systems

Source: https://doi.org/10.1088/1748-9326/abcb38

EVs Can Support the Grid

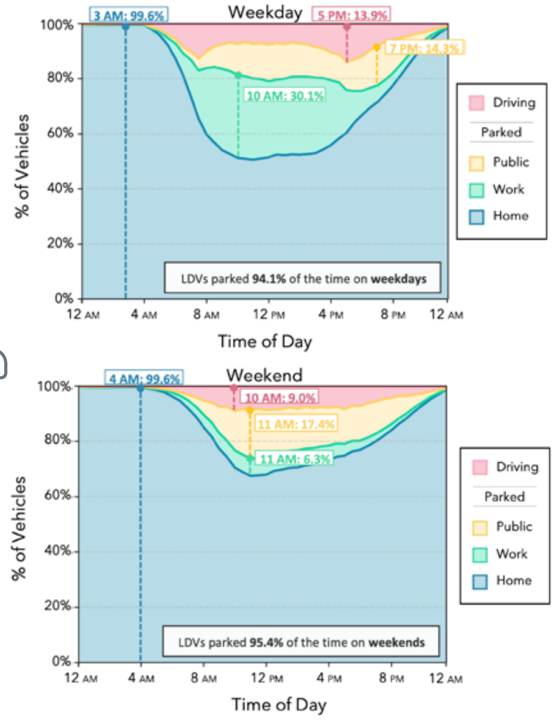
- **Managed charging (V1G)** is shown to consistently provide hundreds of dollars in investment cost savings per EV each year.
- **Bidirectional (V2G)** capability can lead to further cost savings; but the extent depends on system characteristics, EV adoption and willingness to participate, flexibility limitations, and enablement costs.
- Effective V1G and V2G programs recognize that **EVs are first-and foremost-vehicles** (i.e., primary purpose to provide mobility).



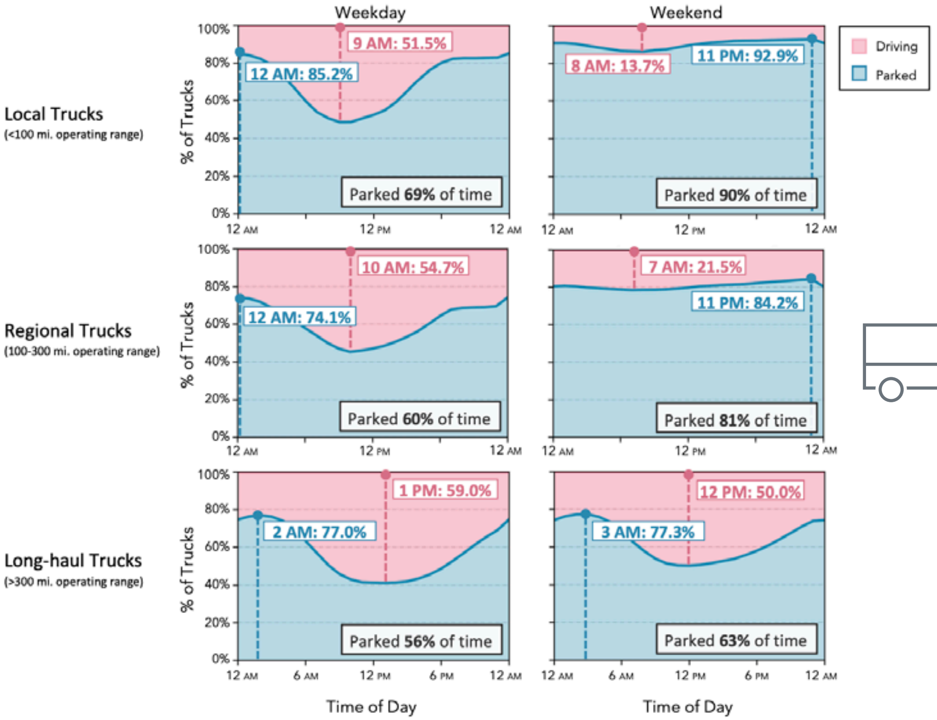
Source: https://doi.org/10.1039/D1EE02206G

Managed Charging: *Doing more with less*

Location of **Personal LDVs** by Time of Day



Heavy-Duty Truck Activity by Time of Day



Light-duty vehicles parked **95%** of the time

Heavy-duty trucks parked approx. **60%** (long-haul) to **75%** of the time (local)

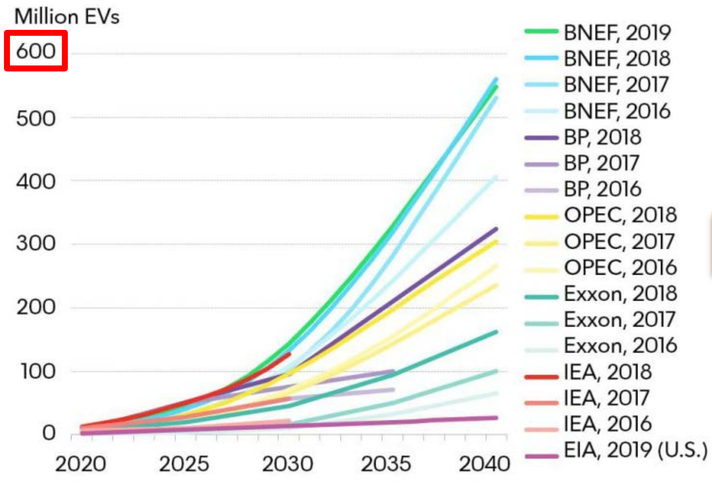
Significant opportunity for **managed charging**!

Supplemental: EV Load Forecasting Challenges

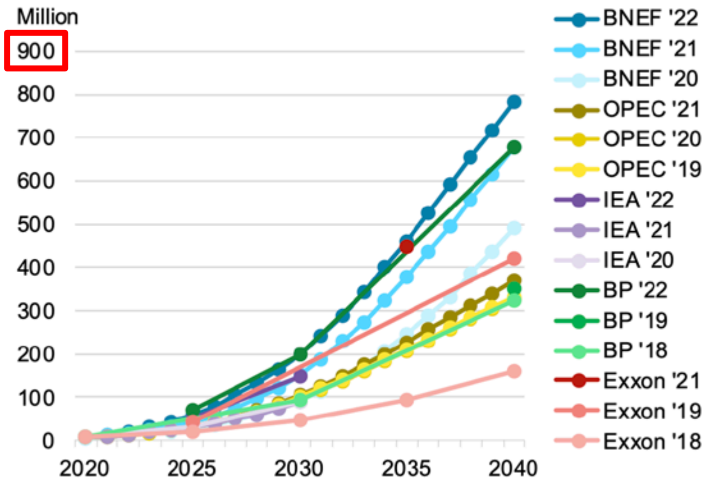
EV Load Forecasting: *Challenges*

Moving Targets: EVs are still a relatively early-stage market. Rapid tech. improvements and new policies are consistently resetting expectations.

EV Outlooks: 2016-2019



EV Outlooks: 2018-2012



Source: BloombergNEF (BNEF), IEA, OPEC, BP, ExxonMobil, EIA. Note: IEA is their base-case (state policy scenario for 2020 through 2022). BNEF includes BEVs and FCVs (excl. PHEVs). OPEC includes BEV, PHEV, and FCV. IEA reports are BEVs only. All other reports include BEV and PHEV.

EV Load Forecasting: *Challenges*

Moving Targets: EVs are still a relatively early-stage market. Rapid tech. improvements and new policies are consistently resetting expectations.

Potential Technology Breakthroughs: Difficult-to-foresee trends and disruptions could impact future EV adoption, use, and charging behaviors in ways that reshape projections.

Energy Monitor

Transport | March 20, 2023

US scientists make breakthrough for long-range EV batteries

A new lithium-air battery could one day replace the lithium-ion battery, and power cars, domestic airplanes and long-haul trucks.

By Oliver Gordon

electrek

California may soon see a lot more driverless robotaxis on the road from GM's Cruise

Scooter Doll | Mar 21 2023 - 8:44 am PT 6 Comments

THE DRIVEN

Solid state battery breakthrough could slash EV costs and recharging time

DECEMBER 13, 2022 · 30 COMMENTS · 2 MINUTE READ · SOPHIE VORRATH

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TECH & SCIENCE

Green Hydrogen Breakthrough Edges Clean Energy Closer to Reality

BY ARISTOS GEORGIOU ON 12/19/22 AT 12:02 PM EST

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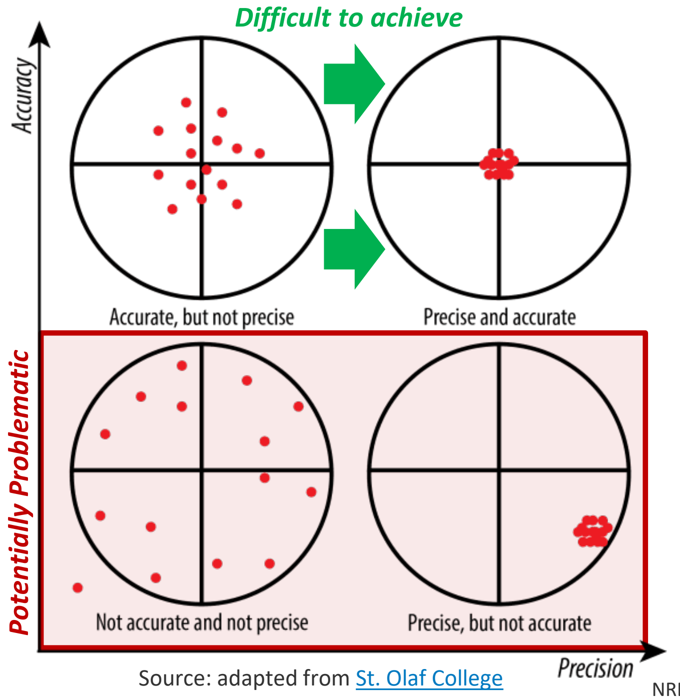
Increased Resolution → Higher Uncertainty:
Sacrificing accuracy for precision can have disastrous consequences for proactive planning.



Source: adapted from St. Olaf College

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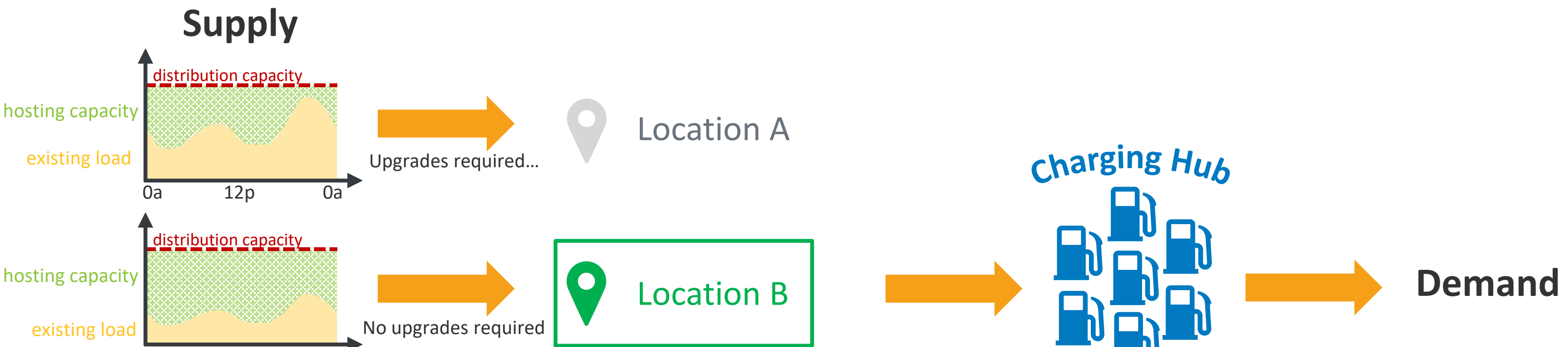

adapted from EPRI

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Data gaps: Useful data is often siloed across multiple organizations.

Uncertainty in EV Load Projections

*More **concentrated** electricity demands*

↓

High uncertainty + High impact
*= **more research required!***