Enabling a Sustainable Future

Clean Energy Transition for Transportation Systems: Modeling Implications

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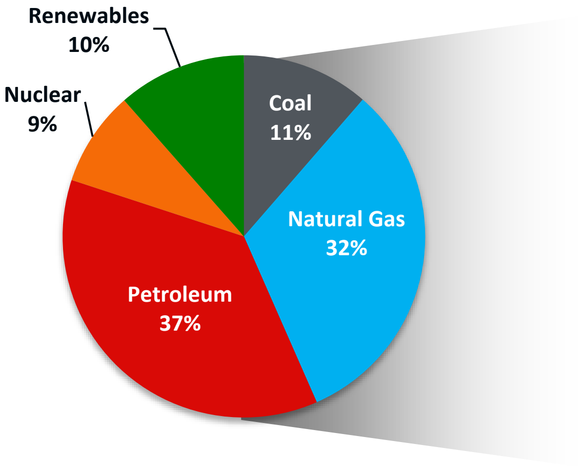
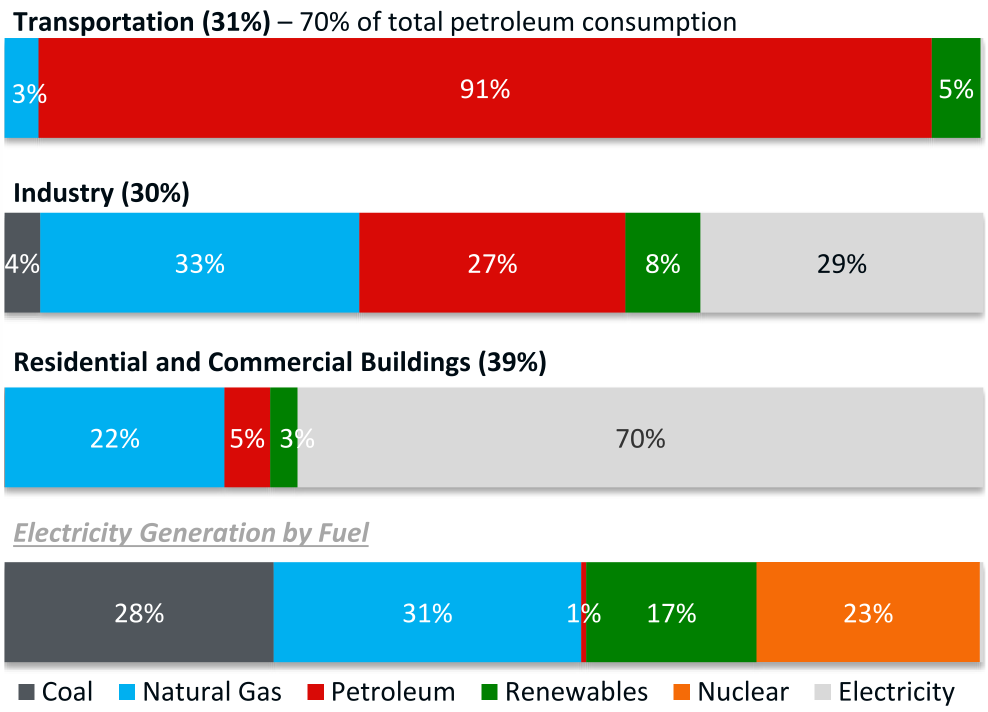
Energy is foundational to our lifestyle, but reliance on fossil fuels has major social and environmental implications

U.S. Primary Energy By Fuel (2019)

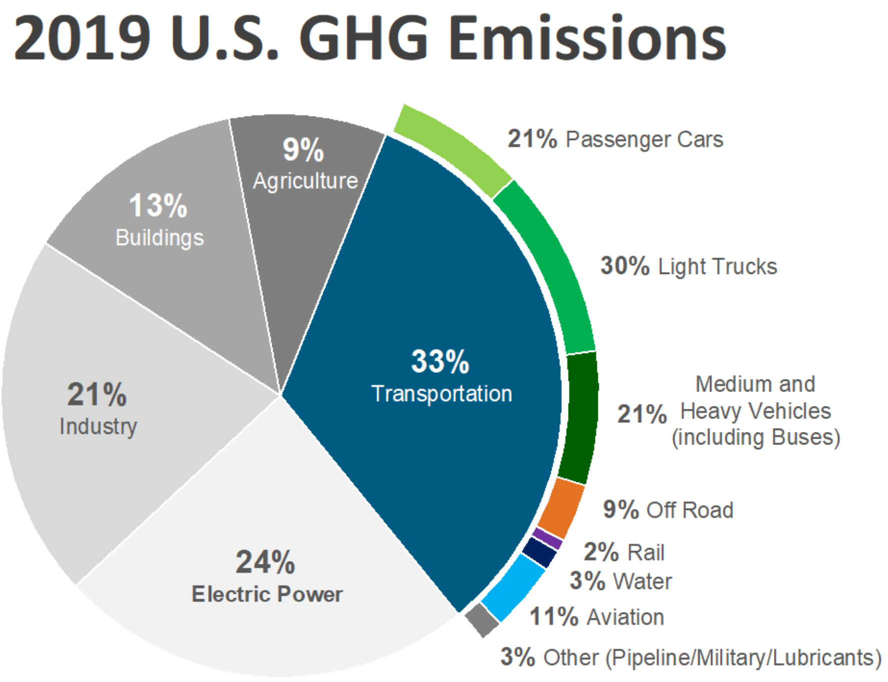


U.S. Energy Consumption by Sector and Fuel (2019)



Source: Muratori, M., 2020. *Integrated Transportation-Energy Systems Modeling* (No. NREL/PR-5400-76566). Data from U.S. Energy Information Administration Annual Energy Review

Transportation is the least-diversified energy sector. Usually considered "hardest to decarbonize" but finally ripe for change

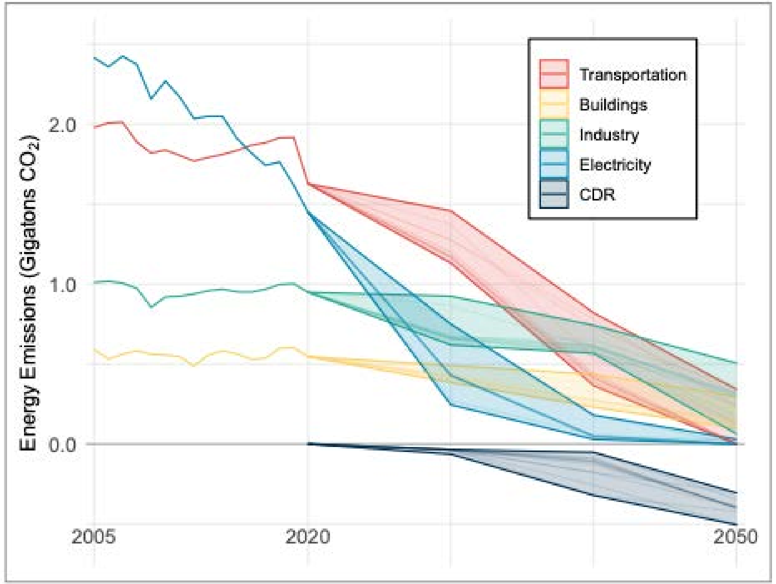


Source: NREL. Data from EPA

- Transportation is the **largest source of US GHG emissions**
  - 50% of energy expenditures
  - Largely responsible for local pollution
- Provides **essential access** to services and economic opportunities
  - Must **support growth** in mobility demand and options
  - Different applications require **multiple solutions**

U.S. TRANSPORTATION DECARBONIZATION

- The Long-Term Strategy of the United States establishes a goal of **net-zero greenhouse gas emissions by no later than 2050 and a 50-52% reduction by 2030** (from 2005 levels) in economy-wide net greenhouse gas emissions.
- The **sense of urgency is high**, and the time to act is now to reach these goals.
- Transportation projected to remain largest source of emissions until 2040, but on a **pathway to 80-100 emissions reduction by 2050**
  - What does this pathway look like?



Informing the Transformation to a Sustainable Mobility Future

Evolving Mobility Options

Shared mobility, automation, telepresence, micromobility, etc.

Locus of Choice

Heterogeneities of people, markets, and places and influence on decisions and tech adoption

Electric Vehicles

Need for greater spatiotemporal resolution & assess flexibility

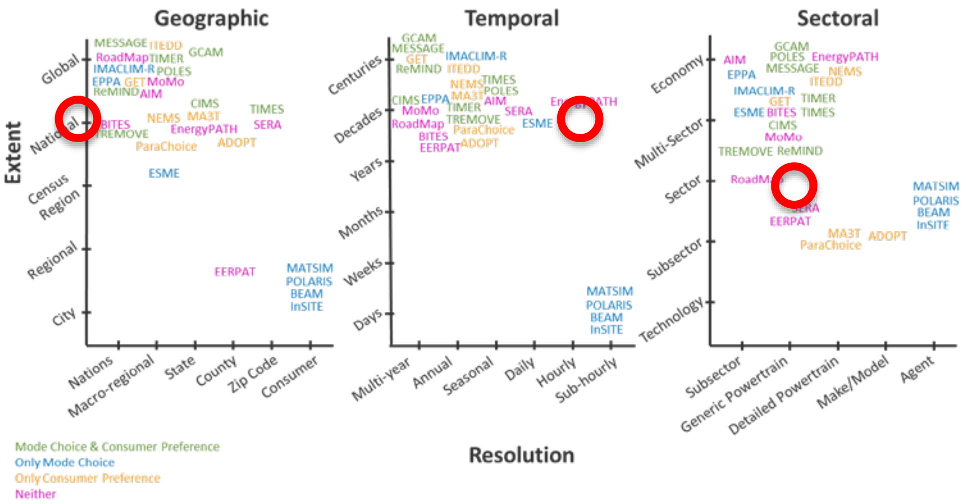
Energy Systems Integration

Transition away from fossil, and integration with the energy system

Modeling Implications

Future integrated mobility-energy systems models must evolve to be able to capture and explore future mobility technologies and systems:

1. **Emerging trends** (new ownership/business models, alternative fuels, automation)
2. **Locus of choice** (heterogeneities of people, markets, and places and their influence on decisions and technology adoption)
3. **Spatiotemporal resolution** (to capture energy systems interactions)
4. **Multi-sectoral dynamics** (supply-demand integration, especially with the grid)



"Future Integrated Mobility-Energy Systems: A Modeling Perspective"

1. New Technologies and Business Models Are Disrupting Mobility Options

Shared Mobility

Mobility on Demand

Goods on Demand

Connected & Automated Vehicles

Emerging Fuels & Powertrains

New Modes of Transport

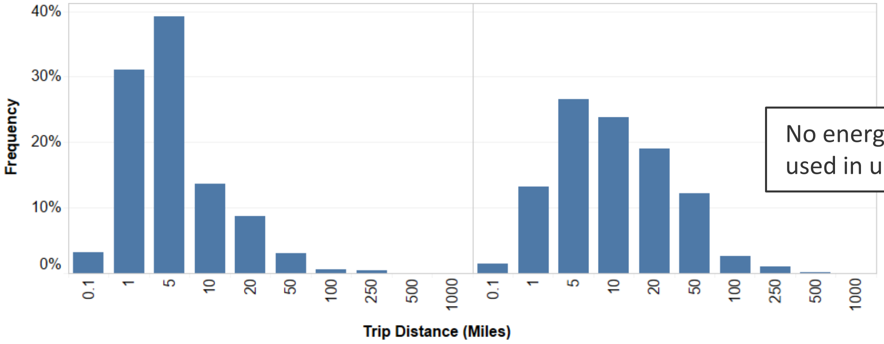
2. Locus of Choices: differences in travel demand and travel choice by sociodemographic and geographic levels

TEMPO

Example of **different trip distributions by household type**

Smaller, low-income, urban household
- High proportion of short-distance trips

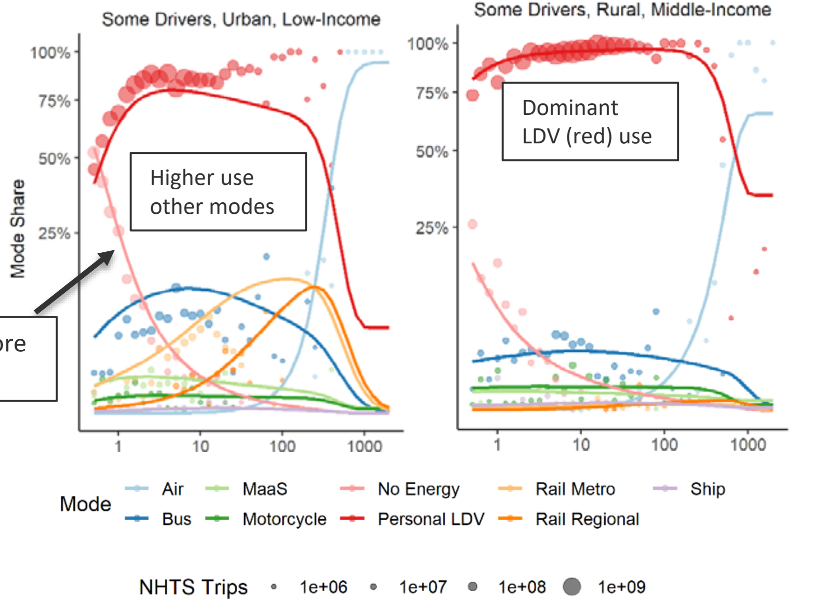
Larger, middle-income, rural household
- Trips distributed over greater distances



No energy (pink) more used in urban areas

Example of **mode choice by household type**

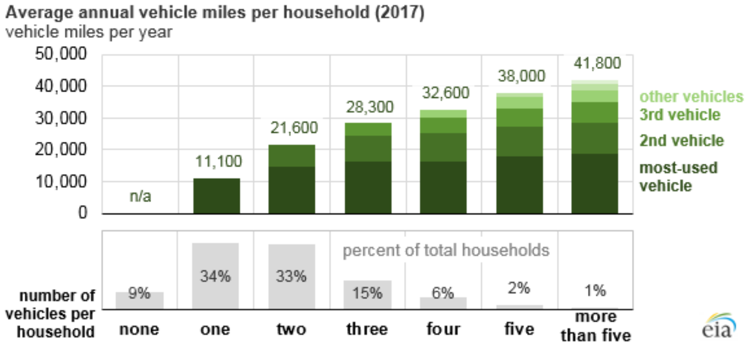
TEMPO mode calibration (lines) compared to NHTS data (dots) share



2. Important to capture nuances to estimate energy use/emissions implications

Not all vehicles are equal, and *X* EVs on the road can lead to widely different impacts. **TEMPO's unique representation of household travel demand provides new insights on adoption opportunities and energy/emissions implications**. Several factors determine energy use and emission benefits:

- **Vehicle use**: in a 2-vehicle household (33% of household), the primary vehicle is driven ~2X of the 2nd vehicle
- Different **vehicle classes** have +-40% fuel economy
- **Household bins (composition, income & urbanity)** have substantial variation in driving behavior (~70% more VMT between highest and lowest bin)
- **Location**: different vehicle classes distributions greatly and different temperatures impact energy use over the year
- **Charging** location and timing is critical for grid integration.

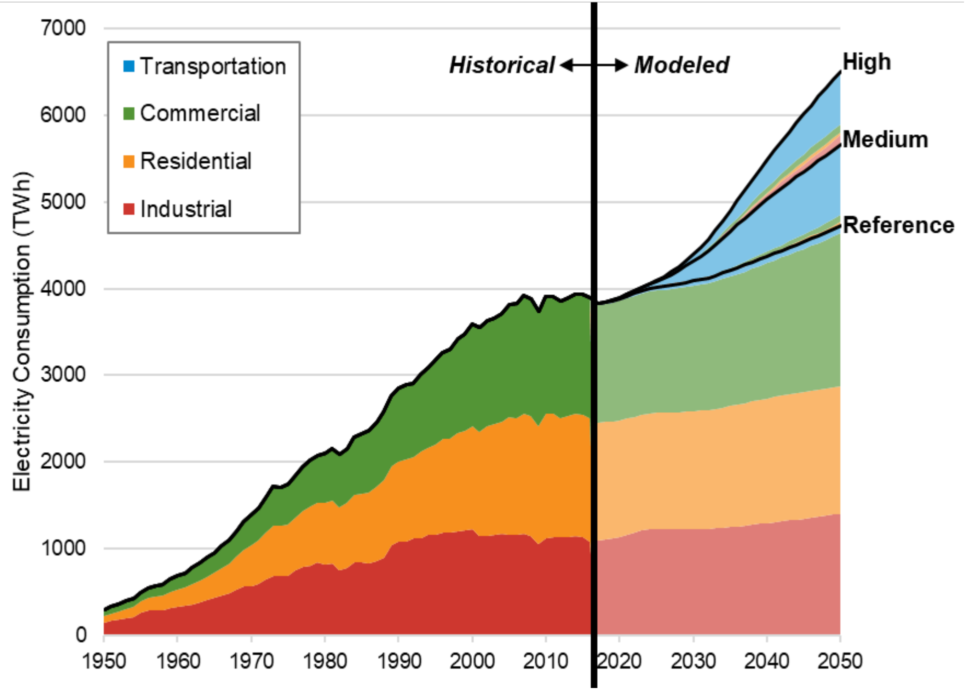


Source: EIA based on NHTS data

3. Impact of Widespread Vehicle Electrification

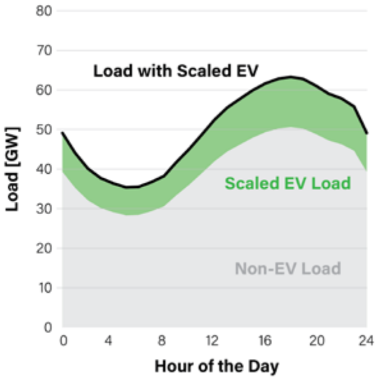
- Electric vehicles (EVs) profoundly disrupt the transportation sector and lead to **far-reaching consequences for electricity system:**
  - **Largest source of load growth** as share of electricity use could increase from 0.2% in 2018 to 23% of electricity consumption in 2050
  - **Unmanaged charging of EVs** can stress existing grid infrastructure, possibly leading to operational, reliability and planning challenges both at the bulk and distribution levels

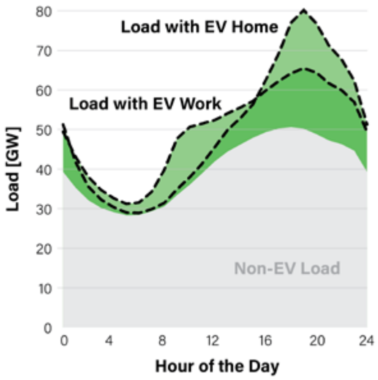
NREL's Electrification Futures Study



3. *When* and *where* EV charging occurs will be as critical as *how much* electricity is needed

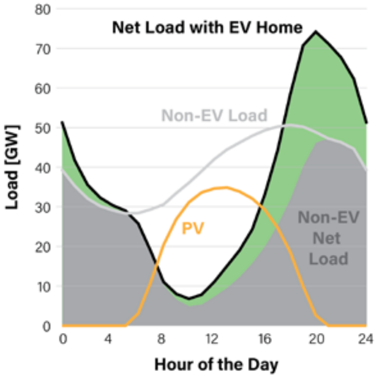
a) ASSUMPTION:
EV charging is often assumed to simply scale up electricity demand.

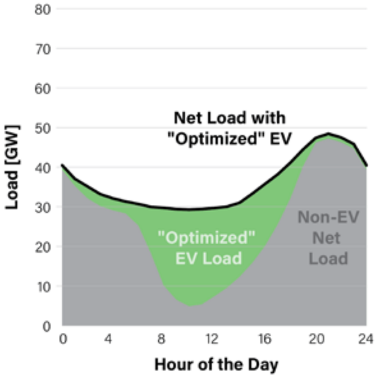




b) COMPLEXITY:
Future EV charging could change the shape of demand, depending on when and where charging occurs.

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





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

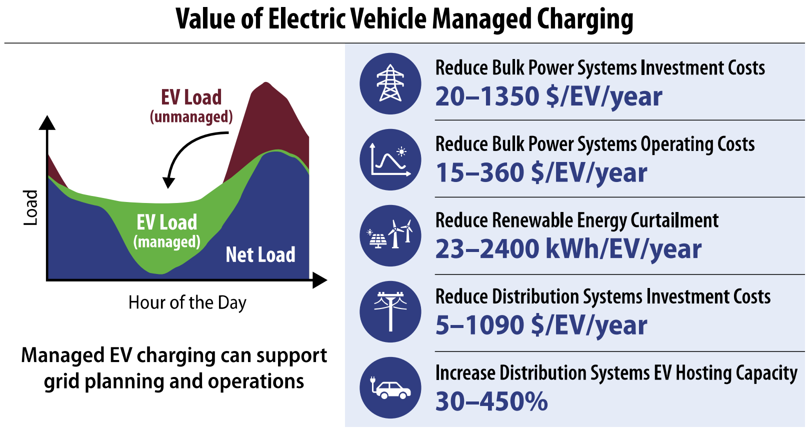
New class of models needed to assess the integration opportunities of EVs on the power system

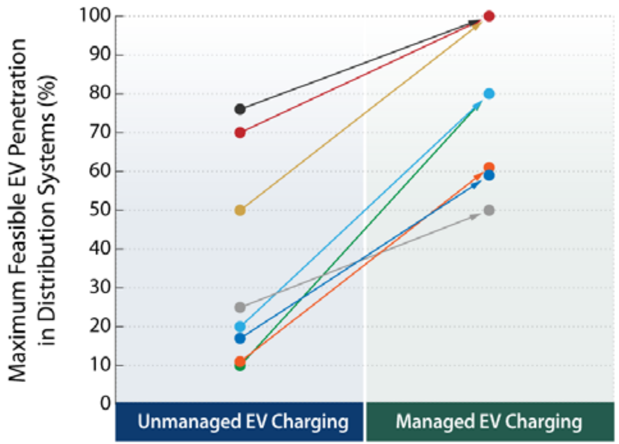
Source: *Muratori and Mai, 2020*

3. Smart EV charging enables synergistic improvement of the efficiency & economics of mobility and electricity systems

Vehicles are underutilized assets parked ~96% of the time: **managed EV charging can satisfy mobility needs while also supporting the grid**:

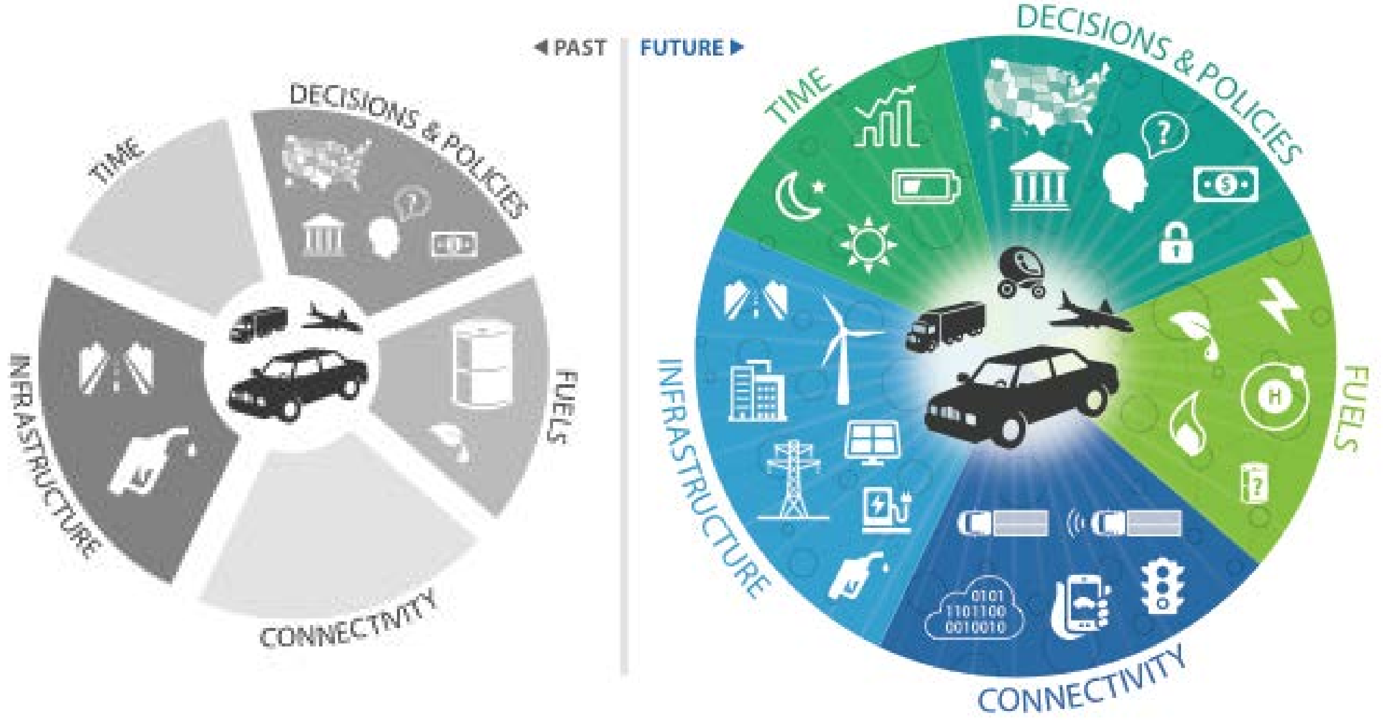
- Demand-side flexibility offers **grid benefits over multiple timescales**
- Supports and **complements the expected large-scale renewable** deployment





Sources: Muratori *et at.* 2021 & Anwar, Muratori, *et al.* 2021

4. After over a century or petroleum dominance, we envision a future transportation system that will be optimally **integrated** with smart buildings, the electric grid, and other infrastructure to **fully leverage and support renewable energy** and achieve an economically competitive, secure, and sustainable future for all.



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Questions?

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Abstract

Transportation is currently the least-diversified energy demand sector, with over 90% of energy use coming from petroleum. As a result, transportation recently became the largest source of GHG emissions in the U.S. and mobility needs for passenger and freight are growing rapidly. However, after over a century of petroleum dominance, new disruptive technologies and business models offer a pathway to decarbonize the sector. Transportation is at a turning point. On the horizon lies a future where affordable and abundant renewable electricity can be used to power cost-competitive battery electric vehicles (EVs) and produce energy-dense low-carbon fuels enabling to fully decarbonize transportation systems across all modes.

Exploring the clean energy transition for the multitude of different transportation systems requires new analytical modeling and approaches. This talk reviewed current work at the National Renewable Energy Laboratory (NREL) to develop and use innovative tools and analytics approaches to inform the transformation to a sustainable mobility future and the integration of transportation systems with the broader energy sector.