Holistic Modeling of Future Transportation Energy Use and Emissions: Transportation Energy and Mobility Pathway Options (TEMPO) Model

PI: Paige Jadun (presenter) & Matteo Muratori
Project Team: Catherine Ledna, Arthur Yip, Chris Hoehne, Brennan Borlaug
National Renewable Energy Laboratory
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DOE Vehicle Technologies Program
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VAN050

Project Overview

Timeline

- **Project start date**: 11/14/2022
- **Project end date**: 09/30/2025
- **Percent complete**: 10%

Budget

- **Total project funding**: $1,500,000
  - **DOE share**: 100%
- **Funding for FY 2022**: $0
- **Funding for FY 2023**: $500,000

Barriers

Uncertainty about the future of mobility complicates forward-looking technology evaluation and R&D prioritization (Vehicle-Mobility Systems Analysis 2020 Roadmap)

- Pathways to achieve an **equitable and sustainable transportation future** are uncertain; **rigorous and comprehensive analysis tools** are required to inform multi-objective decisions
- **Improved modeling capabilities will enable analysis of:**
  - What does the **future of mobility** look like?
  - What are the **ranges of possible scenarios** for how people and goods will move in the future?
  - How will changes impact **future R&D portfolios**?

Partners

(TEMPO Steering Committee)

- California Air Resources Board
- Electric Power Research Institute
- ExxonMobil
- Ford
- ClimateWorks
- Boston University
- Stanford University
- University of California, Davis
- Energy Information Administration
- US Department of Transportation
- Oak Ridge National Laboratory
- Pacific Northwest National Laboratory

Project Relevance

Motivation

- The transportation sector is on the verge of a radical transformation – pathways to achieve full decarbonization remain highly uncertain and are rapidly evolving
- Continuous **development of analytical models** is required to answer evolving research questions

Summary of transportation decarbonization strategies from U.S. Transportation Decarbonization Blueprint

Objectives

- Maintain and continue development of NREL's TEMPO model to enable exploring **new transportation energy use and emissions analyses**
- Support DOE in answering high-urgency, quick-turnaround analysis requests to support decision-making

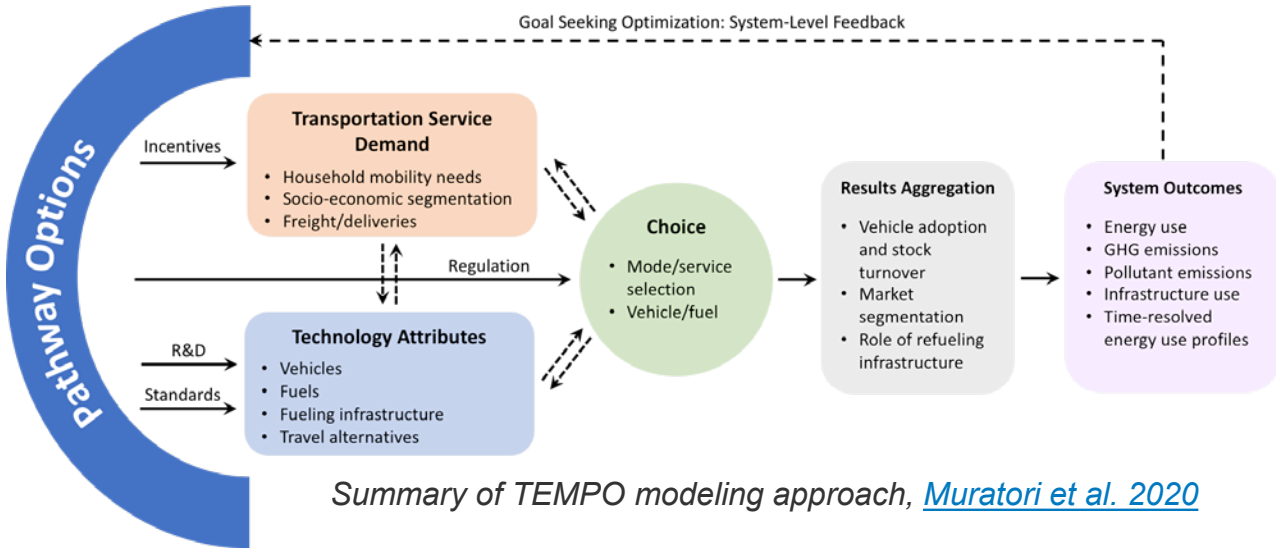
Impact

- Advancement of modeling and analysis state-of-the-art to answer timely questions with an increased degree of confidence and fidelity covering all modes of passenger and freight travel in the US
- Improved ability for DOE and other stakeholders to **gain insights into the future evolution of the transportation sector** and promote the adoption of sustainable transportation solutions in a way that is equitable and synergistic with the broader energy system

Blue text refers to priorities for VTO Analysis program

Project Approach

TEMPO is a comprehensive transportation demand model designed to explore long-term scenarios of energy use across all modes of transportation



Summary of TEMPO modeling approach, Muratori et al. 2020

Project work revolves around TEMPO and is divided into **three primary workstreams:**

Capability Development and Model Enhancement

- Consult with VTO, steering committee to prioritize development
- Document enhancement-related insights
- Support ongoing and upcoming analysis

Model Upkeep

- Train new staff
- Document model
- Update data sources
- Maintain model (code versioning, bug fixes, etc.)

Quick Turn-Around Analysis

- Respond to VTO quick-turnaround strategic requests
- Quickly run scenarios with alternative input assumptions to produce key metrics, visualizations

Project Approach: Why TEMPO?

TEMPO is a key tool in the DOE arsenal to explore future transportation energy use and emissions scenarios across the entire sector

Examples of recent TEMPO applications and insights generated:

Decarbonizing Medium- & Heavy-Duty On-Road Vehicles: Zero-Emission Vehicles Cost Analysis

Ledna et al 2022, https://www.nrel.gov/docs/fy22osti/82081.pdf

TEMPO analysis supported development of the US Transportation Decarbonization Blueprint

- **White House Fact Sheet** on accelerating transition to clean buses and trucks
- **US joins Drive to Zero**
- **Proposed EPA regulations** for Heavy-Duty Vehicles

Exploring decarbonization pathways for US passenger and freight mobility

Hoehne et al. (forthcoming)

- Insights on overall **transportation decarbonization pathways**
- Scenarios for **EMF 37**: Deep Decarbonization & High Electrification Scenarios for North America

Milestones

Milestone	Date
Expand TEMPO steering committee to include one or more members with expertise in energy & environmental justice (EEJ)	FY23 Q1 (complete)
In coordination with the steering committee and VTO, **determine primary modeling capability enhancements** to complete in FY23	FY23 Q1 (complete)
Summary of TEMPO model upkeep activities, updates, and estimated impacts on results for FY23	FY23 Q3
Publication of at least one TEMPO model enhancement and related results and insights for FY23	FY23 Q4
Draft publication of complete **model documentation** and accompanying dataset of TEMPO results for a baseline and one or more alternative scenarios to be made publicly available	FY24 Q2
Publication of at least one TEMPO model enhancement and related results and insights for FY24	FY24 Q4

In addition, the project team holds **regular check-in presentations with DOE-VTO** summarizing TEMPO model and data updates and impacts on results, and reviewing quick-turnaround analyses, prioritization of model enhancements, and the needs and timeline for publication of analysis insights and/or datasets

Technical Accomplishment #1:
Expanded steering committee and held first SC meeting

- The TEMPO steering committee was expanded to include an **expert in energy & environmental justice** (**FY23 Q1 Milestone**) to better support future modeling efforts in this space

- Held first **steering committee meeting** of the project cycle in February 2023 to discuss approaches and value of:
  - Current TEMPO analysis objectives
  - Identification of top-priority model enhancements for FY23 → **feedback contributed to selection of priorities highlighted on the following slide**
  - Modeling of the Inflation Reduction Act impacts in transportation models

Technical Accomplishment #2:
Identified top priority FY23 model enhancements to support broader VTO portfolio

In coordination with VTO and TEMPO Steering Committee, the team identified the top priority model enhancements for FY23:

Related analyses supported by update:

Resolve heterogeneities of light-duty vehicle (LDV) technology adoption with nationally specified exogenous sales scenarios

- Use endogenous adoption formulation to inform exogenous adoption scenarios
- Perform analysis exploring bounds of heterogenous EV adoption

DECARB*, EVs and Bulk Power System (VAN054)

Represent Inflation Reduction Act (IRA) policy impacts

- Model impacts of select provisions in TEMPO, including relevant cross-sectoral assumptions (e.g., electricity-related emissions)

DECARB* demand scenarios

Improve representation of passenger modes beyond personal LDV

- Synthesize literature to develop parameterizations of key dynamics
- Increase resolution of non-LDV passenger modes (e.g., biking/walking, micromobility)

Travel demand management scenarios (VAN055)

*EERE-funded multi-lab effort to identify priority areas for decarbonization research

Not an exhaustive list of possible model updates for FY23; the project will also support additional model enhancements as needs arise

Technical Accomplishment #3:
Initial implementation of targeted LDV sales share scenarios

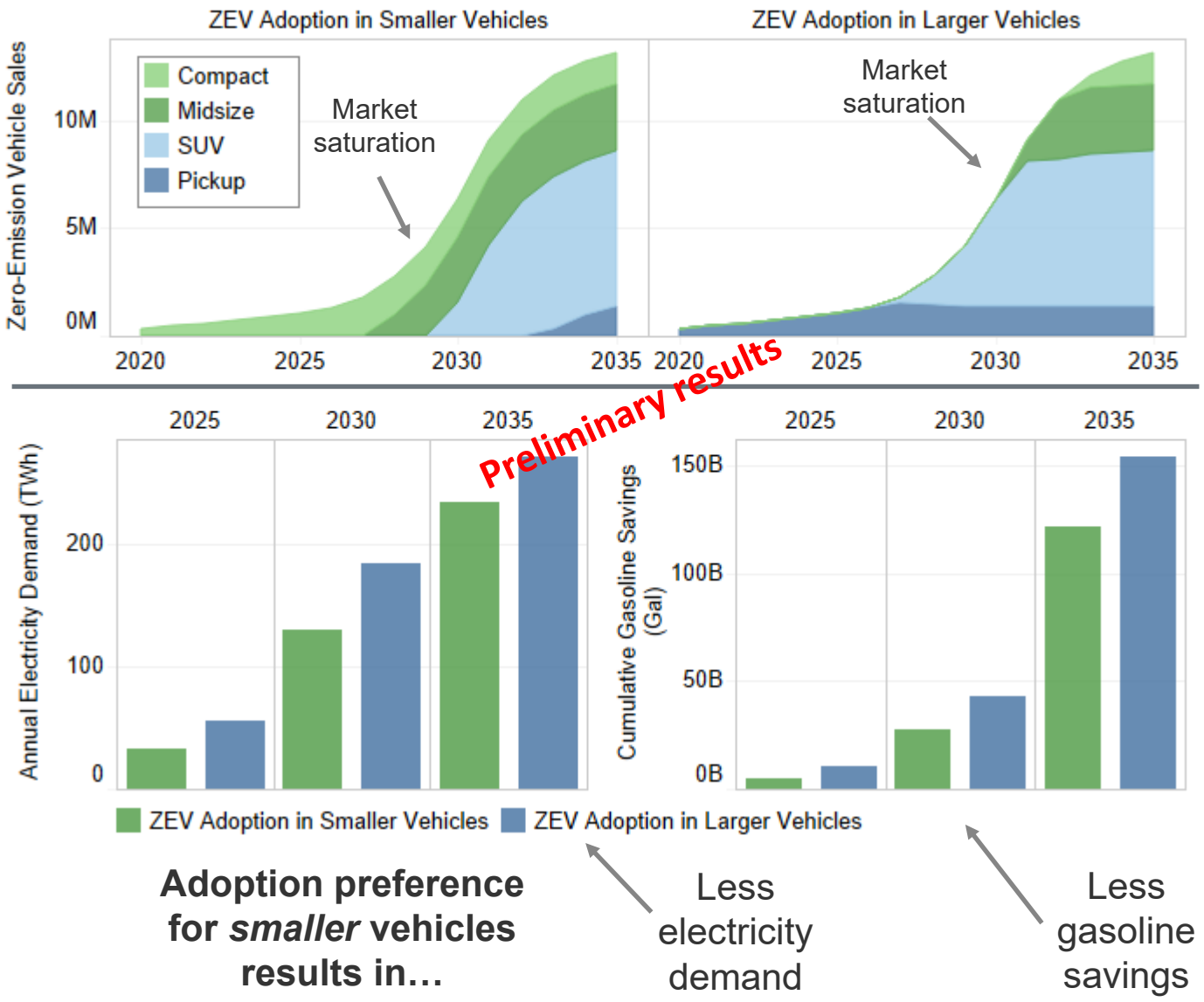
Problem

- For a scenario with exogenous LDV technology shares (e.g., 50% ZEV in 2030), how can we identify **most likely purchasers**?
- How does heterogeneous adoption by vehicle class and household **impact energy use, emissions, charging needs** and/or **vehicle manufacturing requirements**?

Approach

- **Assess bounds** of heterogeneous adoption
- Use **endogenously generated estimates of consumer utility** in TEMPO for different vehicle classes, vehicle technologies, and consumer groups to generate a baseline

Preliminary results show that bounds of heterogenous adoption can **impact cumulative gasoline savings in 2035 by up to 27%**



Adoption preference for *smaller* vehicles results in…

Less electricity demand

Less gasoline savings

Final results will be documented in forthcoming publication (FY23 Q4 Milestone)

Responses to Previous Year Reviewers' Comments

This is the first year in which this project is up for review.

Collaboration and Coordination with Other Institutions

- The **TEMPO steering committee** was established in 2019 to guide model development and identity top priority research questions that TEMPO should address
- Participation consists of members from **government organizations, industry, research institutions, and academia** including:

  - DOE Bioenergy Technologies Office
  - DOE Hydrogen and Fuel Cell Technology Office
  - DOE Strategic Analysis
  - Energy Information Administration
  - US Department of Transportation
  - California Air Resources Board
  - Electric Power Research Institute
  - ClimateWorks
  - ExxonMobil
  - Ford
  - Boston University
  - Stanford University
  - University of California, Davis
  - Oak Ridge National Laboratory
  - Pacific Northwest National Laboratory

For this project, the steering committee provided input to identify the top-priority model enhancements for FY23 and contributed to identification of future enhancements to consider for subsequent funding years.

Remaining Challenges and Barriers

- **New legislation in IRA will impact the evolution of the transportation sector**
  - **Challenge:** Representation of complex and multi-faceted policies (e.g., supply-side domestic manufacturing requirements and fuel production tax credits in IRA) may be difficult in a demand-side model like TEMPO and requires cross-sector integration

- **Representation of alternative, non-LDV passenger modes should be included in transportation decarbonization modeling**
  - **Challenge:** Often, assessing impacts of alternative modes requires higher-resolution modeling than available in TEMPO (e.g., impact of bike lanes, impact of micromobility on access to public transit, etc.)

- **Thorough model documentation and publication of insights is essential to share modeling methodologies with broader analysis community and precipitate analytical advancement**
  - **Challenge:** Modeling capabilities, along with technology and policy landscapes, are rapidly changing, requiring continuous model improvements and corresponding documentation updates

Proposed Future Research

FY 2023

- **Complete LDV adoption analysis:** Complete and submit journal article exploring bounds of heterogenous adoption for nationally mandated sales scenario **(FY23 Q4 Milestone)**
- **Implement IRA representation in TEMPO:** Identify which provisions' impacts can/should be modeled in TEMPO; develop parameter assumptions from literature and/or in coordination with steering committee, DOE
- **Refine representation of non-LDV passenger modes:** Review literature and analysis insights from higher-resolution models (e.g., agent-based models) to inform parametrization of dynamics to model in TEMPO; refinements to include increased resolution of walking/biking modes, inclusion of micromobility options, refinement of mobility-as-a-service and associated impacts.

FY 2024

- **Model documentation:** Release publicly-available TEMPO documentation update; develop documentation processes to support continuous improvement **(FY24 Q2 Milestone)**
- **Modeling priorities**: In coordination with steering committee and VTO, identify new set of top priority model enhancements to target in FY24 and implement

The project team will also continue to respond to quick-turnaround strategic requests from VTO as they arise

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

Summary

The **transportation and energy landscapes are rapidly changing**, requiring the continuous development of tools to tackle evolving research questions.

Enhancement, maintenance, and application of the TEMPO model will **enable and directly support larger VTO programmatic goals** to understand and support adoption of efficient and **sustainable transportation technologies and solutions** in a way that is **equitable and synergistic** with the transformation of the broader energy system.

Key Project Takeaways

- **Top-priority enhancements** identified for FY23 include
  - Refinement of LDV technology adoption modeling
  - Incorporate IRA policy impacts into the model
  - Improved representation of non-LDV passenger modes
- Model enhancements **support opportunities for new and ongoing** analysis in DOE portfolio
- Engagement with **diverse steering committee** will inform future modeling and analysis priorities
- Project structure is intended to **flexibly respond to critical analysis needs** as they arise
- Project is **on track**

Thank You

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Paige.Jadun@nrel.gov

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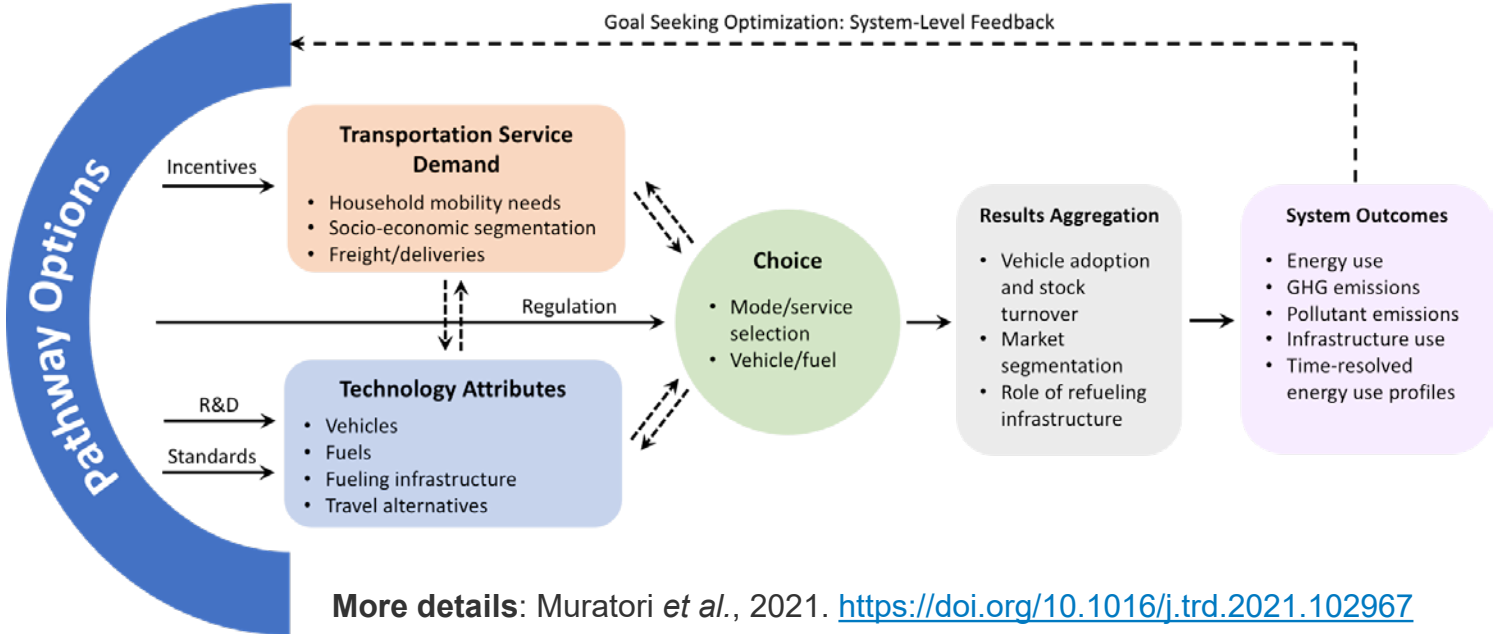
Technical Backup Slides

What is TEMPO?

The Transportation Energy & Mobility Pathway Options (TEMPO™) model is a **comprehensive transportation demand macro model to explore long-term scenarios** of energy use across all transportation segments and to integrate with large, multisectoral studies.



More details: Muratori *et al.*, 2021. https://doi.org/10.1016/j.trd.2021.102967

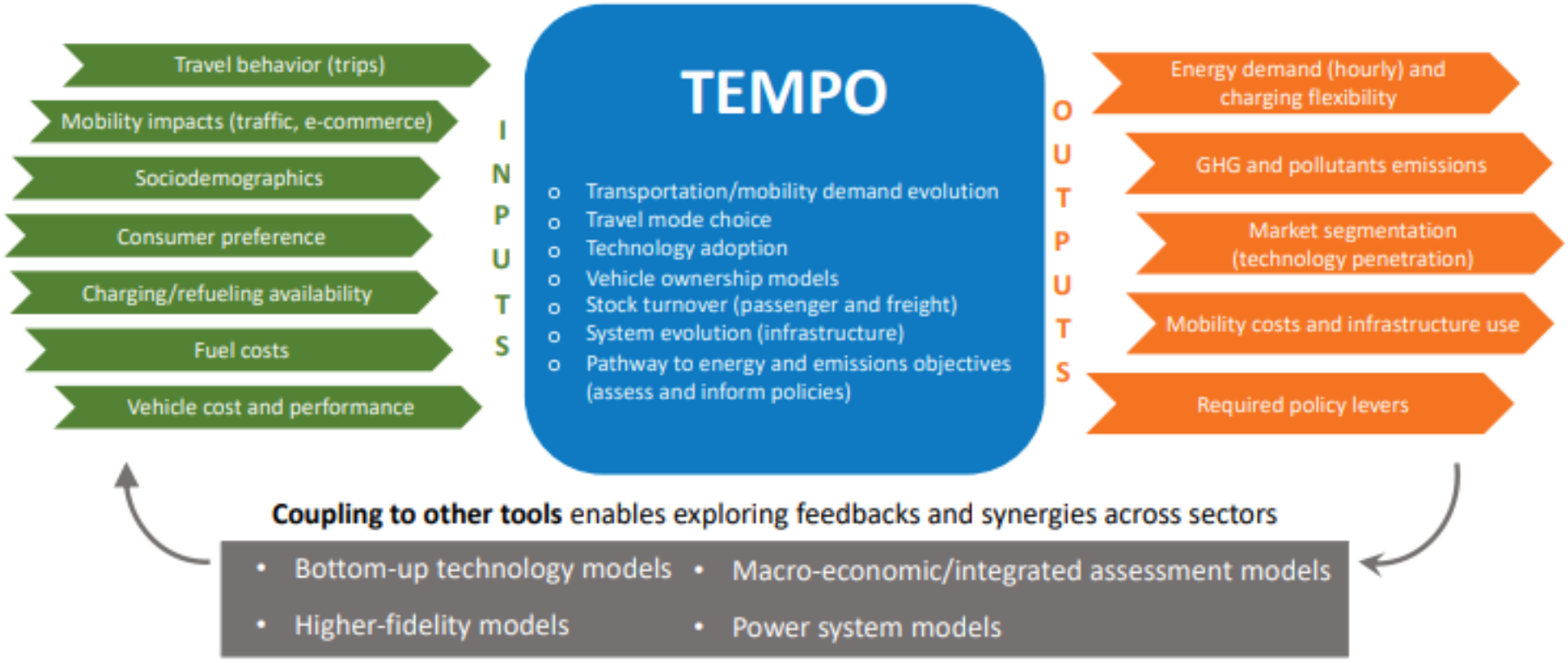
TEMPO models domestic passenger and freight travel demand across all travel modes and projects their evolution over time to answer questions like:

- What is the potential for radical transformations of transportation supply and demand?
- How might interconnections with other sectors and infrastructure evolve?
- Which fuels/technologies will be adopted and in which market segments?

Modeling framework envisions coupling with other tools to inform inputs and assess the broader impacts of TEMPO results

Alternative scenarios can be run by varying inputs on technology, consumer behavior, system attributes, etc. - where inputs can be informed by other models

TEMPO generates **internally consistent outputs to estimate impacts** on technology adoption, energy use, emissions, etc. which can further inform additional analyses



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

In-progress model update addresses regional heterogeneity of vehicle survival and impact on EV sales

Problem

- Review of county-level electric vehicle (EV) adoption results showed an overestimation of EV sales in rural counties in exogenously specified sales share scenarios → further analysis indicated that vehicle retirements were being overestimated in those counties due to higher average vehicle age ("preference" for used vehicles), leading to higher-than-expected EV sales

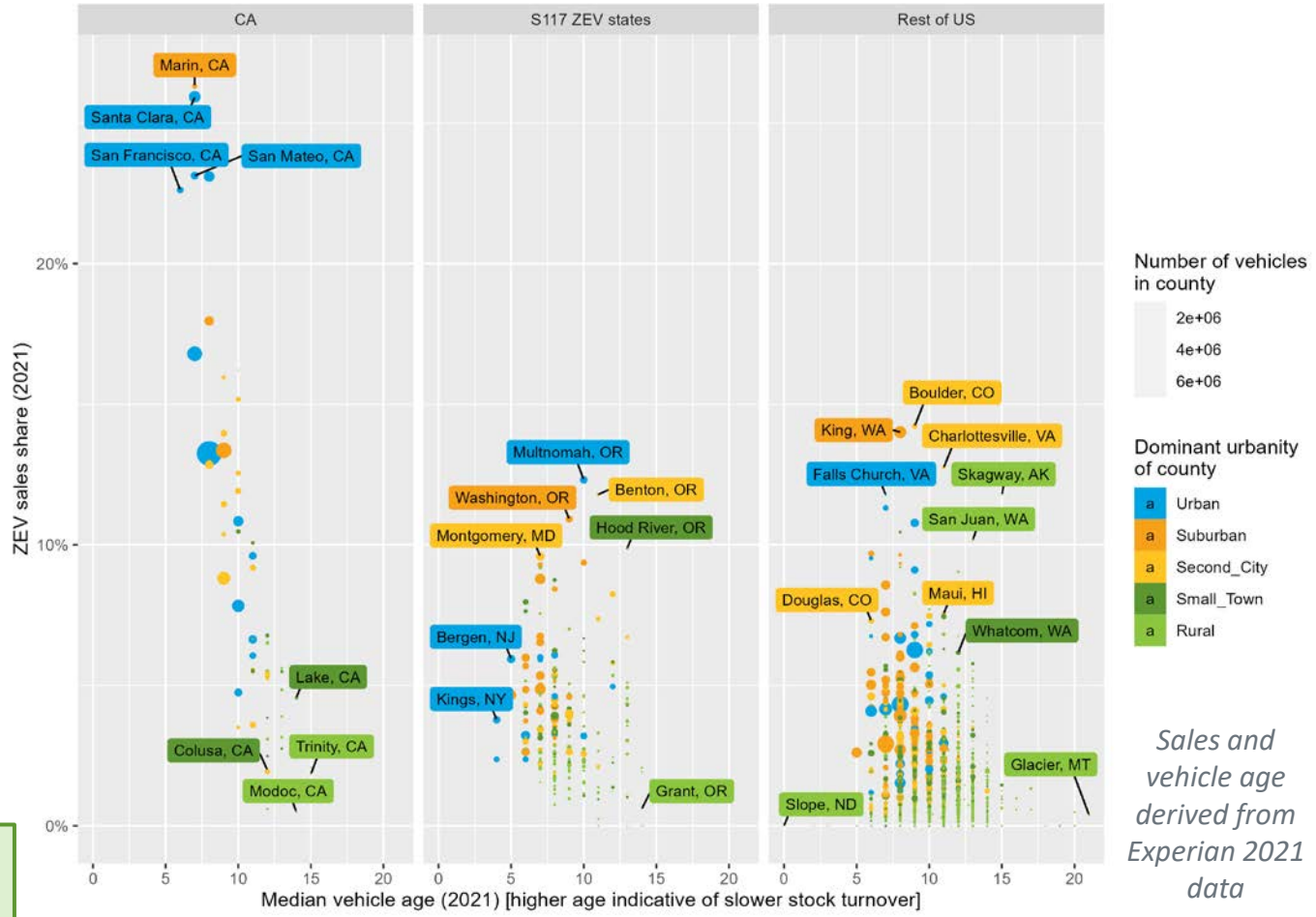
Context

- Historically, counties with higher EV sales share also have typically had newer vehicles/faster turnover, mostly in California - however, this may change with more widespread EV adoption
- To make better regional EV adoption projections, both EV sales share and typical vehicle age need to be considered in modeling

Approach

- Regional vehicle survival curves and transfer assumptions will be developed to help TEMPO reflect heterogeneous ownership by vehicle age and its impact on EV roll-out

Expected impact: Improved regional projections of EV sales and associated energy use/load profiles



Sales and vehicle age derived from Experian 2021 data

Additional model enhancements were identified as potential future work

Possible Enhancement	Expected Impact and Analysis Questions Enabled
Model the used-vehicle market: Enable the modeling of vehicle diffusion across different household and/or freight bins to capture differentiation of adoption and use between first owners and used vehicle purchasers, impacts on energy use and emissions.	How does EV adoption and use differ across household income categories? How does truck adoption driven by first (high-use) ownership impact penetration potential of alternative fuel vehicles?
Better represent equity implications of transportation sector transformations: Improve capabilities to represent equity considerations of transportation scenarios, particularly in the context of deep decarbonization.	Improved modeling at household bin level can support tradeoff analysis and multi-objective decisions that compares impacts of personal mobility, public health, and GHG emissions, across differing demographics.
Improve detailed representation for freight travel modes beyond trucks: Build on segmentation of freight travel by distance bin and add additional technology resolution and operating characteristics for non-truck freight modes.	Better estimation of the potential penetration of alternative technologies and/or business models and the impact on energy use and emissions.
Enhance capabilities to model changes in freight logistics and/or vehicle operations: Implement functionality to reflect changes in freight logistics (e.g., shift to shorter driving distances to accommodate range-limited ZEVs, impact of ecommerce)	Explore how shift in freight operations from the norm can impact ZEV technology adoption, and the resulting impact on energy use and emissions.
Update calibration to newer Annual Energy Outlook (AEO): Update calibration year to 2023 using newer version of AEO. Potential to assess effort and create automated processes for calibration for subsequent updates needs.	Ensure TEMPO reflects most current available data, and possible increase efficiency of further calibration updates.
Represent biofuel availability and allocate use across modes: Include endogenous adoption of biofuel based on cost (including possible cost of carbon), policy drivers, and/or decarbonization potential to allocate the limited biofuel availability across modes.	Endogenously track biofuel use compared to supply, and better assess implications for adoption across modes on system costs and energy use/emissions.
Add optimization capabilities to reach economic or emissions-based objectives: Add an optimization wrapper to the model to explore scenarios that minimize system wide costs, emissions, or other specific objectives.	Identify decarbonization pathways that result in the lowest cost, lowest emissions, least behavioral change, etc. How do changes in technology, policy, behavior impact the optimal solution?
Implement adoption and use of automated vehicles (AVs): Estimate projected trajectories of cost and efficiency of automated vehicles and develop methodology for quantitatively representing non-monetary value (e.g., safety, convenience), and how these factors impact adoption, energy use and emissions.	Impact of AV adoption on energy use and emissions explore crucial feedbacks, including rebound effects of more convenient travel, reverse urbanization (people willing to live farther from job centers), and increased system efficiencies (lower travel times).
Create workflow to efficiently leverage GREET estimates of emissions and energy use: TEMPO includes tailpipe and well-to-wheel emissions factors for the various fuels as model inputs. Develop an automated workflow to process GREET for use in TEMPO.	Expand emissions scope to include lifecycle vehicles emissions, non-CO2 emissions, and water use implications, and increase efficiency of updating input assumptions.

TEMPO has been used extensively by DOE to provide useful insights on a variety of topics

- Scenario analysis of **sustainable technology adoption for medium- and heavy-duty on-road vehicles** was used to inform development of the **US Transportation Decarbonization Blueprint**
  - Results documented in Ledna et al. 2022: https://www.nrel.gov/docs/fy22osti/82081.pdf, Promoted by DOE: https://www.energy.gov/articles/doe-projects-zero-emissions-medium-and-heavy-duty-electric-trucks-will-be-cheaper-diesel
  - U.S. National Blueprint for Transportation Decarbonization: https://www.energy.gov/eere/us-national-blueprint-transportation-decarbonization-joint-strategy-transform-transportation
- **Light-duty vehicle EV adoption scenarios to inform adoption goals consistent with net-zero scenarios**, estimate the number of EVs on the road, and project future battery manufacturing requirements and electricity demand *(publication forthcoming)*
- Development of **sector-wide transformation scenarios to estimate the total amount of electricity, hydrogen, and biofuels needed to support transportation decarbonization** over time used to refine assumptions for end-use demand trajectories in an NREL 100% Clean Grid Study, enabling consistency between analysis efforts.
  - Clean Grid Study documented Denholm et al. 2023: https://www.nrel.gov/docs/fy22osti/81644.pdf
- Emissions **impacts of potential zero-emission vehicle mandates and other proposed policy in the Inflation Reduction Act** for the Office of Policy
- Estimation of LDV **EV load profiles and associated flexibility** to inform value of managed charging to the **bulk power system**
  - Hale et al. 2022: https://www.nrel.gov/docs/fy22osti/83404.pdf