Transportation Energy Evolution Modeling (TEEM) Program

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Building and Transportation Science Division

Oak Ridge National Laboratory

for

2021 U.S. DOE Vehicle Technologies Office Annual Merit Review

June 22, 2021

Project ID: van021

Overview

- Timeline
  - 10/2019-9/2022;
  - 50% completed
- Budget
  - FY20: $500k (received)
  - FY21: $500k (received)
  - FY22: $500k (expected)
- Barriers Addressed
  - providing analytical capabilities in support of the U.S. DRIVE Partnership
  - continually maintaining up-to-date, validated vehicle component models, and developing appropriate test procedures as new technologies emerge

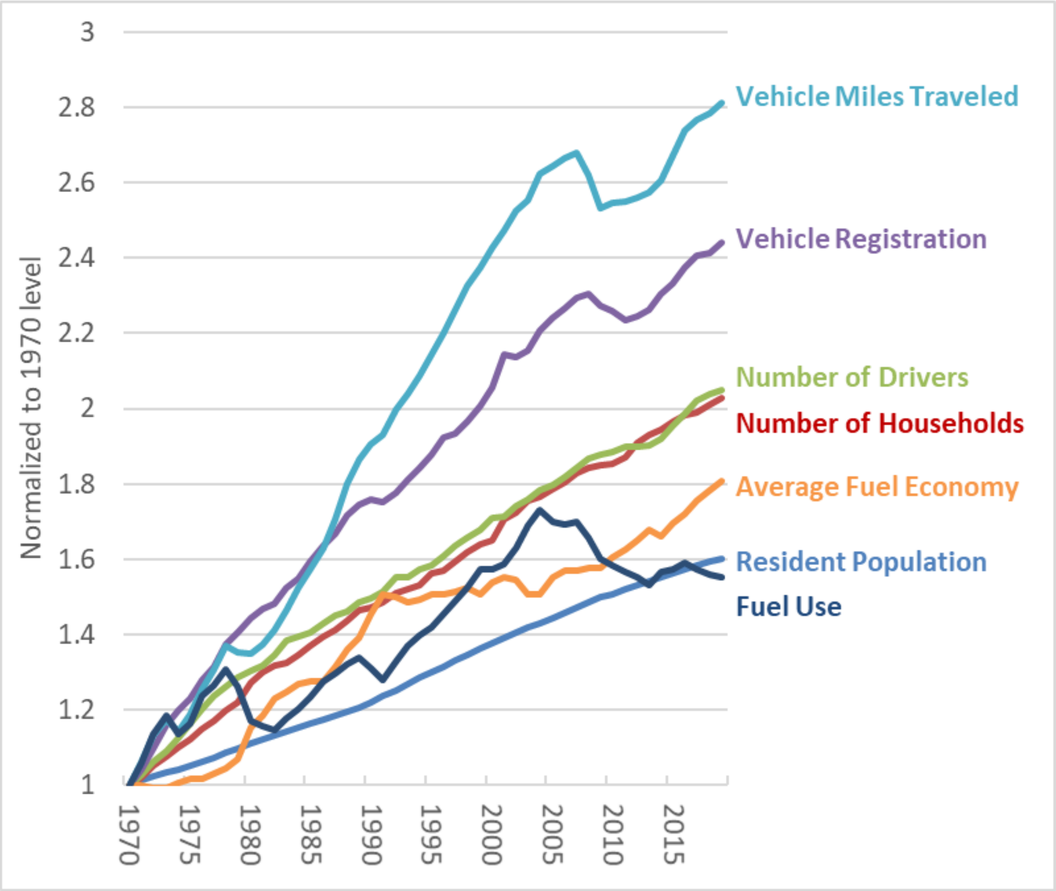
- Team/Collaborators
  - ORNL team: Zulqarnain Khattak, Wan Li, Zhenhong Lin (PI),Nawei Liu, Shawn Ou, Fei Xie
  - Industry: Romeo, Aramco
  - Academia: U. of Tennessee, Iowa State U., U. of South Florida
  - Gov/Lab: DOE, ANL, NREL
  - International: Tsinghua University, CATARC

Note: some acronyms explained in backup slides

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

Transportation energy transition --why it matters?

- DOE VTO mission, energy security, 2050 carbon neutrality
- Transportation: petroleum-based, largest GHG emitting sector, but vital for economy and quality of life
- DOE & industry improve vehicle technologies: battery, light-weighting, engine, mobility
- Market acceptance is key but complicated
  - Technology impact is enabled by adoption
  - Consumers see technologies differently than engineers/scientists/economists
  - Suppliers seek more profits and less risks



Key trends associated with light-duty vehicles in the U.S. 1970-2019 (Transportation Energy Data Book)

TEEM goal — to develop/apply modeling tools on transportation energy transition issues

- Tackling energy transition challenges
  - How to efficiently and effectively transition and transform the current petroleum-based transportation energy system into a socially more beneficial one
  - Climate change, equity, energy security, employment, resilience
- Developing a market dynamics modeling platform
  - Continuation and expansion of the MA3T model
  - Development of new issue-driven models (e.g. REVISE, MA3T-TruckChoice, BREVO)
  - Collaboration and integration with VTO models and other tools
  - Scope: all highway vehicles, DOE and U.S. relevancy, comprehensiveness, user-friendliness, credibility, collaboration
- Outcomes: tools, publications, communications

On track to meet all milestones

Milestone Description	Month/Year	Status
Progress update presentation to HQ on xFC impact on battery degradation (consumer perspective)	12/31/2020	Complete
Progress update presentation to HQ on xFC maximum impact and range assurance	03/31/2021	Complete
Progress update presentation to HQ on PHEV vs BEV analysis	06/30/2021	On schedule
Progress update presentation to HQ on MA3T improvements and new developments	09/30/2021	On schedule

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

Quantify adoption-based impacts of transportation energy technologies and decisions

Data

Consumer
- time value, price elasticity, driving pattern

Technology
- Battery cost, fuel economy, range utilization

Infrastructure
- Charger location, number, power; fuel prices

Policy
- Incentive, CAFE, ZEV mandate, HOV access

TEEM models

- **MA3T**: US LDV
- **MA3T-TruckChoice**: US HDV
- **MA3T-MC**: mobility choice
- **REVISE**: charging infra.
- **TransitMo**: multimodal travel
- **BREVO**: battery/w xFC
- **MOR-BEV**: optimal e-range
- **NEOCC**: industry response

Decisions

Consumer: choice of fuel, range, mode, VMT

Manufacturer: vehicle price, product diversity

Infrastructure provider: charger network design

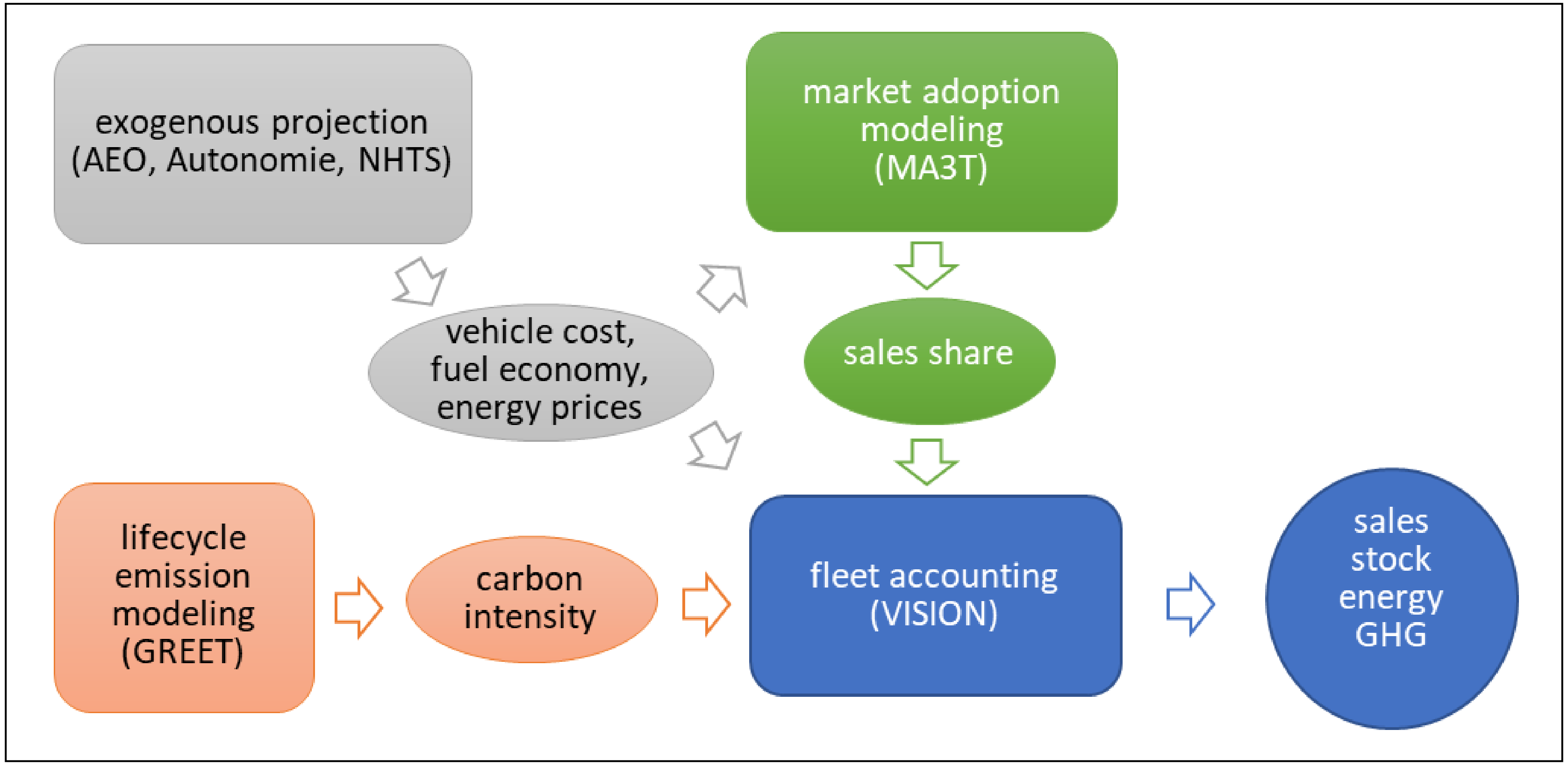
Policy maker: Incentive design, regulation design

Impacts

- ZEV sales
- Petroleum use
- Electricity load
- GHG emissions
- Jobs
- Equity
- Air pollution
- Cost-effectiveness

MA3T+VISION+GREET for adoption-based carbon neutrality analysis

- VISION takes PEV shares from MA3T and upstream gCO2/kWh from GREET under various AEO grid mix scenarios and outputs total WTW CO2 emissions

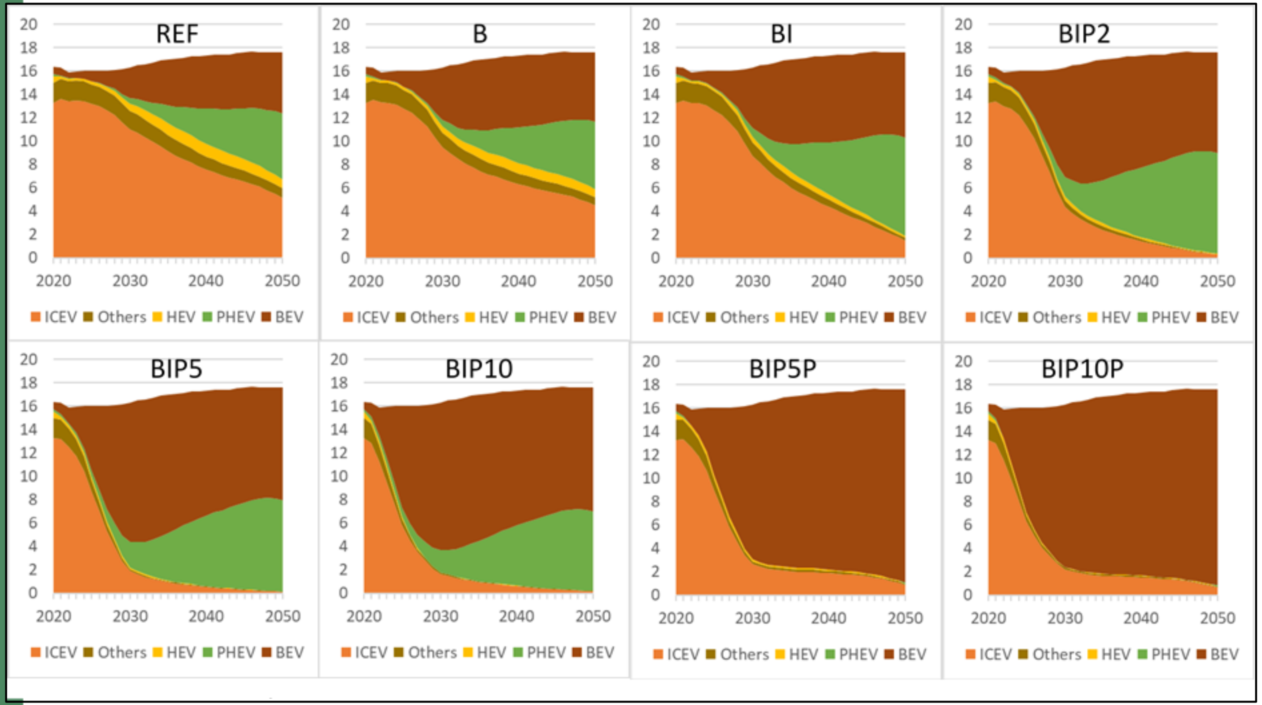


U.S. LDV 2050 carbon neutrality analysis

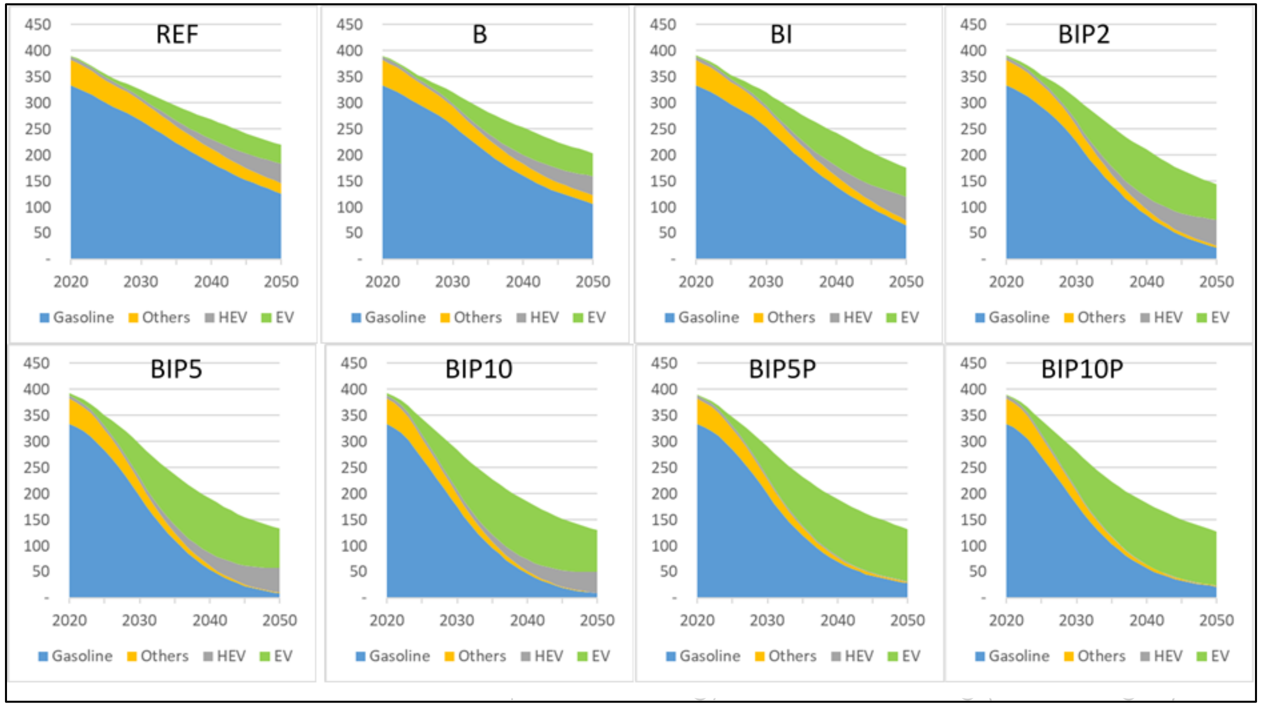
- Approach: MA3T+VISION+GREET+AEO Renewable
- Battery and C.I. improvements required, but not sufficient
- Policy forcing and PHEV force-out may be necessary
- PHEVs can be competitive
- Grid decarbonization needs acceleration

Label	Scenario name	Battery	Charging	Policy forcing	PHEV force-out
REF	Reference	base	base		
B	BCost	adv	base		
BI	BCost+Infra	adv	adv		
BIP2	BCost+Infra+Policy2usd	adv	adv	$2/gal	
BIP5	BCost+Infra+Policy5usd	adv	adv	$5/gal	
BIP10	BCost+Infra+Policy10usd	adv	adv	$10/gal	
BIP5P	BCost+Infra+Policy5usd+PH Out	adv	adv	$5/gal	yes
BIP10P	BCost+Infra+Policy10usd+P HOut	adv	adv	$10/gal	yes

Projected annual sales by powertrain type (million) in US

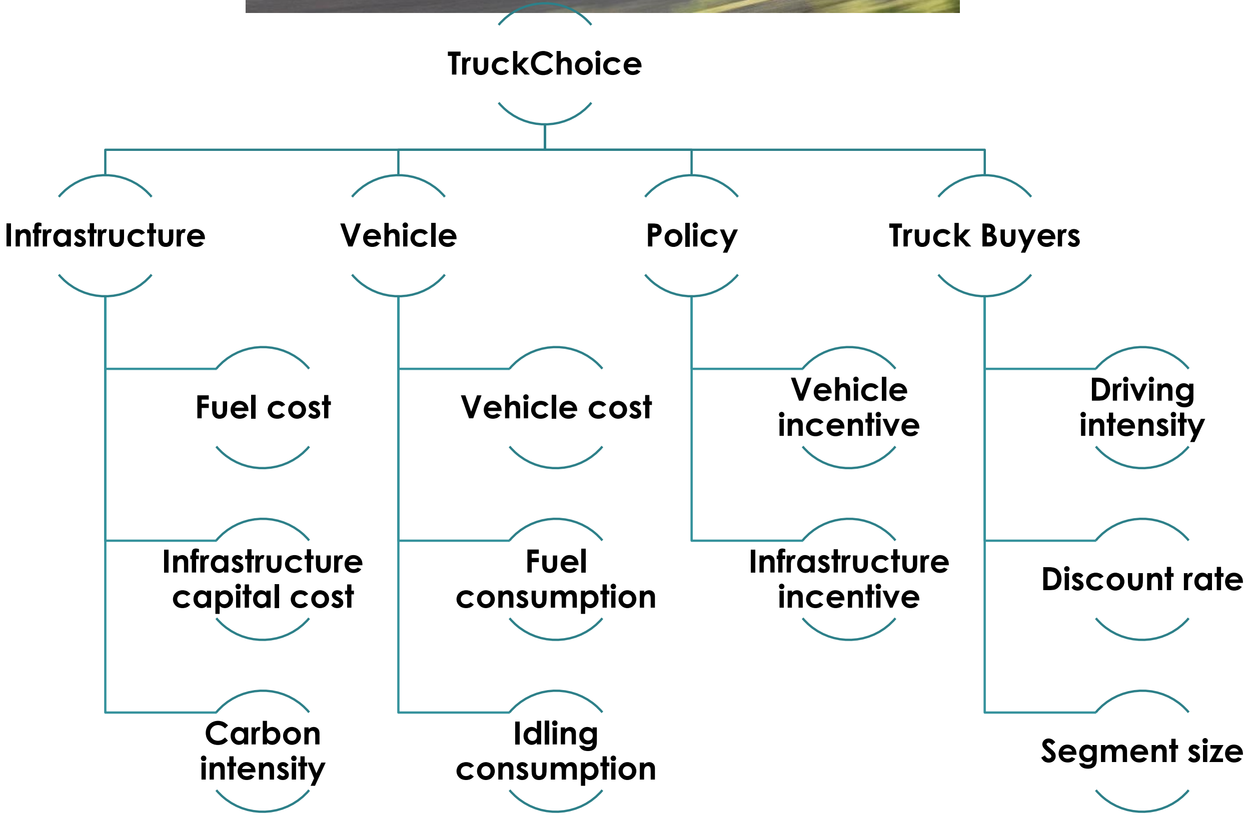


Projected lifecycle GHG emissions (MMTCe)



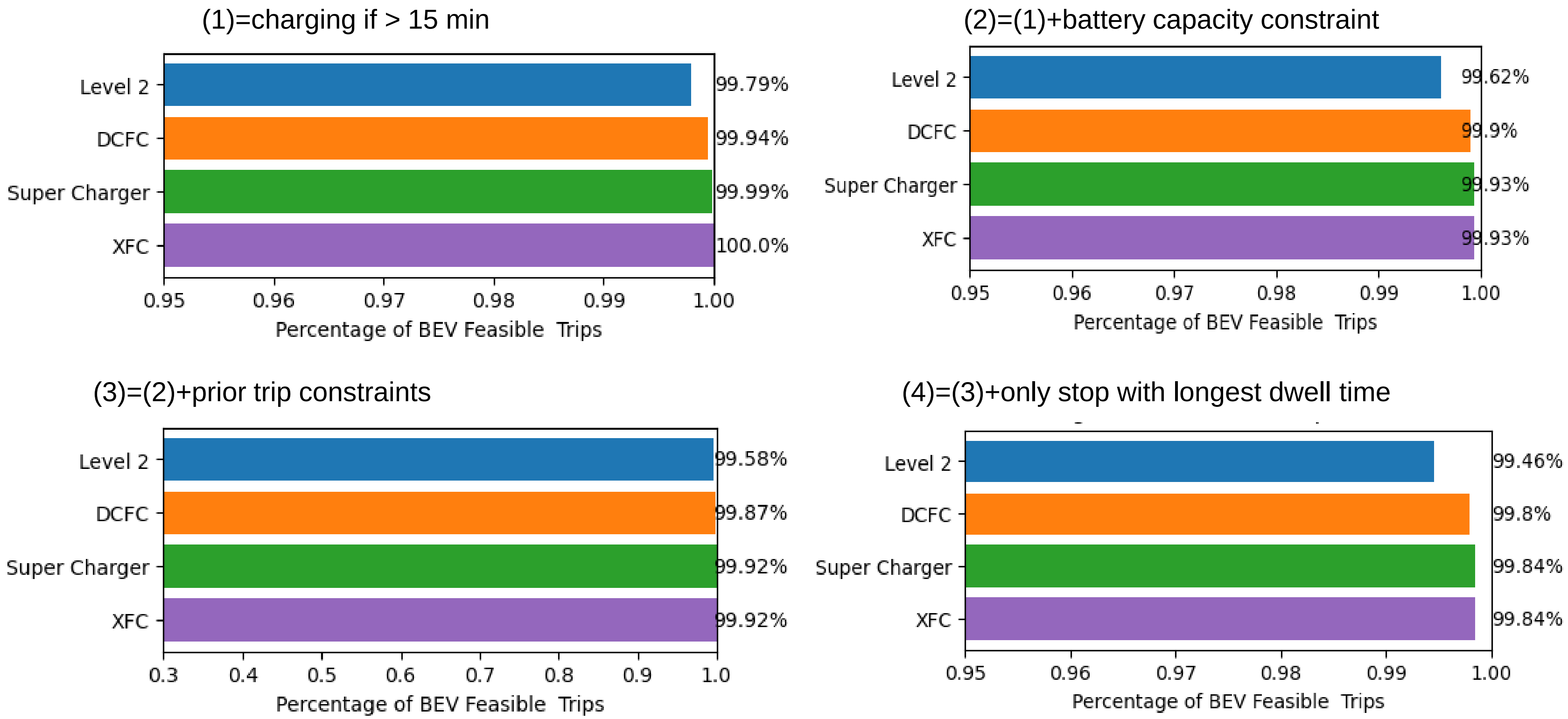
MA3T-TruckChoice Model Development

- Total cost of ownership (TCO) – based framework:
  - Vehicle cost, fuel cost, refueling cost, etc.
  - Cost components based on VTO's TCO study and literature
- Stochastic simulation with random factors, to capture truck procurement heterogeneity, such as
  - Annual VMT
  - Discount rate
  - Refueling behaviors (e.g., budget time and time value)
- Implemented in Python
- Results have been generated

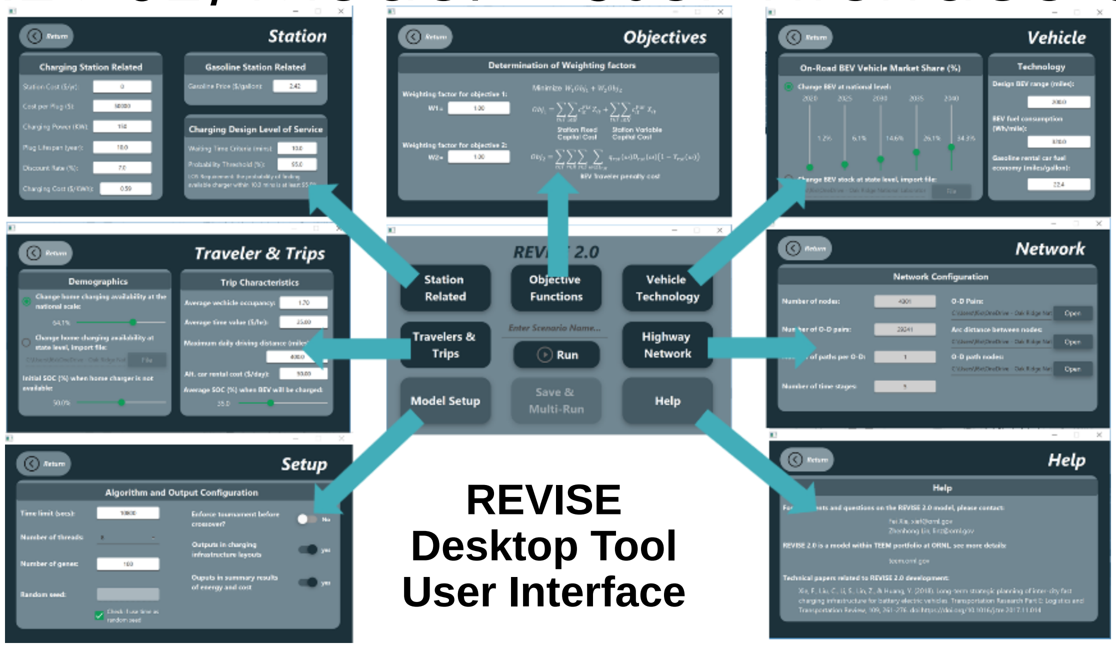


Understanding value of extreme fast charging

- Setup: what are priority and cost-effectiveness of level 2, DCFC, Super Charger, and xFC for public use?
- Assuming a battery electric vehicle with 150 miles of driving range; charge only when dwell time >15 min
- Increasing charging power may not significantly improve BEV daily driving range
- DCFC can be comparable to Super chargers and XFC in terms of improve BEV feasibility
- xFC may be more valuable for occasional emergency use and for commercial vehicles than for light-duty regular use



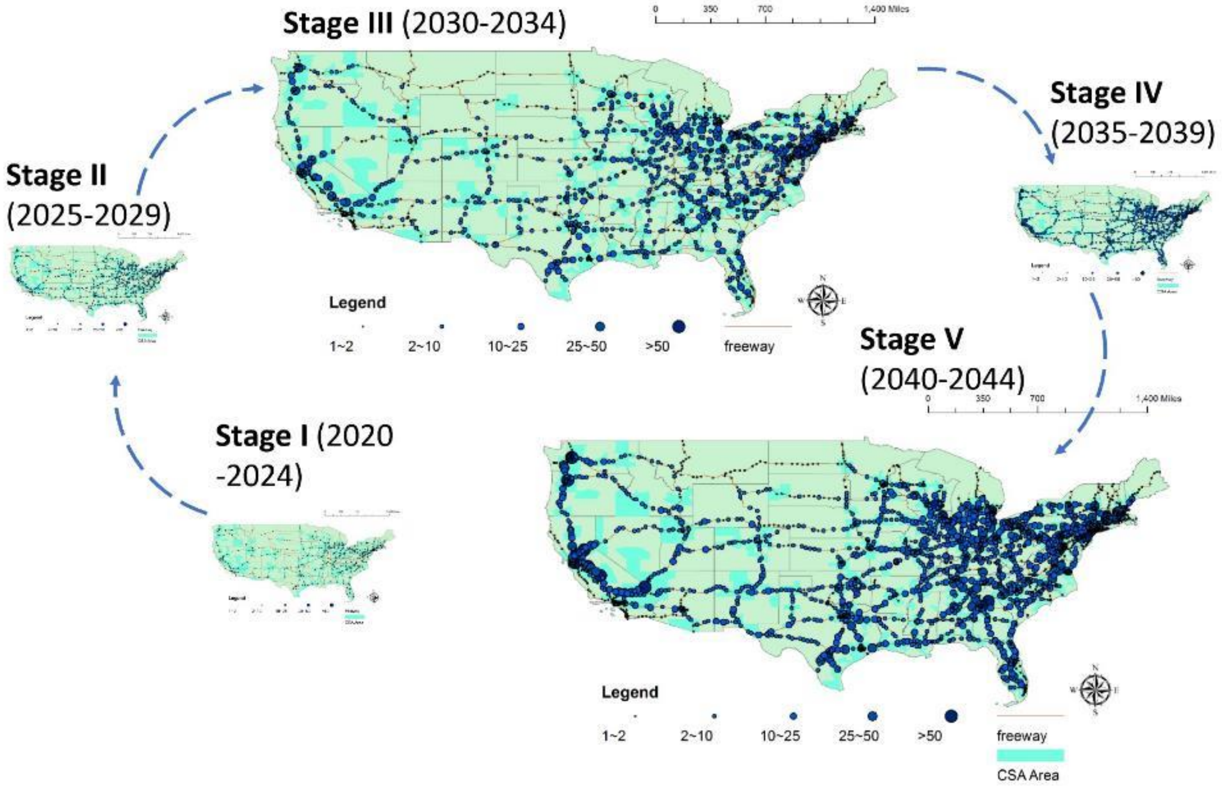
Regional Electric Vehicle Infrastructure Strategic Evolution (REVISE) Model -- User Interface and Results



REVISE Desktop Tool User Interface

Scenario analysis on infrastructure planning based user-specific assumptions on technology, behavior, economic factors, etc.

Results on Charging Multi-year Infrastructure Evolution



- Multi-page GUI
- Pre-loaded with default assumptions
- Mouseover with help descriptions
- Capture some geographic variations in parameters (e.g., EV adoption)
- Software Download: https://teem.ornl.gov/Account/Login?returnUrl=/resources

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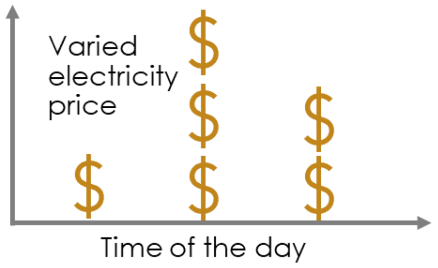
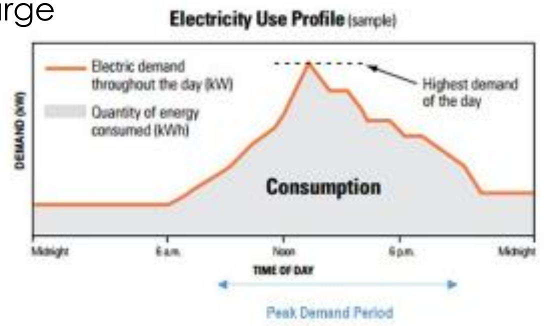
Optimization of Workplace Charging (WPC) Design and Operation

- WPC is an important alternative to home charging
  - Home charging is difficult in some places: 34% of occupied housing units **do not have** a garage or carport (FOTW #1058)
  - Opportunity to extend range with relatively longer dwell time
- Design and operations of WPC are sophisticated
  1. Limited space and budget
  2. Which charger to choose, and how many? – Level 1, level 2, and DCFC.
  3. Travel patterns and charging demands are different between employees
  4. Varied electricity rate and demand charge
  5. Energy and environment concerns
  6. Equity between users: electric vehicles vs. conventional vehicles
  7. Stochastic systems – how to design and operate WPC considering randomness



Demand Charge



Source: we-energies.com

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Optimizing workplace charging facility deployment and smart charging strategies☆

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ARTICLE INFO

Keywords:
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Optimization
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Smart charging

ABSTRACT

This study introduces a workplace charging (WPC) optimization model that maximizes the total satisfied electric miles of employees' plug-in electric vehicles, subject to a given annual budget. The model optimizes both planning decisions of charger number and power levels and operation decisions of charging spot assignment and charging schedule for the given temporal distribution of charging demands and varied electricity prices. Results of experiments based on national average travel data indicate that the actual WPC strategy varies by budget level. Through optimization, the strategy could reduce impacts of the varied electricity price by shifting charging schedules to periods when electricity prices are low. Also, the model is expanded to study the trade-off between providing WPC and addressing consequence of degraded charging service by including the per-mile shadow cost of unsatisfied charging demand. We observe that their relative competitiveness mainly depends on the actual shadow cost of WPC.

1. Introduction

Establishing adequate charging infrastructure support is an important step to alleviate range anxiety (fear of insufficient vehicle ranges) and increase public acceptance of plug-in electric vehicles (PEVs). The structure of this charging infrastructure support is hierarchical (NRC, 2015). In particular, the primary and secondary charging points should be at home and workplace while public charging plays a supporting role when PEV trip distance exceeds the electric range. According to the national household travel survey (NHTS) (USDOT, 2009, 2018), most trips, in terms of vehicle miles, are home- and work-related. Therefore, most charging activities are still expected to occur at home and the workplace. As the primary charging resource, home charging could be convenient where there is a designated parking garage or carport at home, but is usually difficult to implement in multifamily residential buildings (Peterson, 2011). The recent American Housing Survey (AHS) (Census Bureau, 2017) revealed that only two-thirds of all occupied housing units in the U.S. have garages or carports. Therefore, in addition to home charging, work-place charging (WPC) is an important secondary charging solution. Accordingly, this study aims at developing a mathematical model to evaluate WPC infrastructure requirements and provide guidance on WPC operations.

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Responses to Previous Year Reviewers' Comments

- The TEEM project was not reviewed in 2020, but at the 2019 AMR. The 2019 reviewers in generally reacted positively on research relevancy, publication productivity, model validation, model usefulness, and international engagement, with the following concerns or suggestions.
- "As the team seems very output oriented, the reviewer cautioned that the team continues to make sure that the core mission remains in front and center as the project team moves forward with new models and validates existing ones."
  - Response: we have continued to update data and re-calibrate the models. We communicated frequently with the HQ manager to ensure we focus on the core mission and useful work.
- "This reviewer also stated that specific information with respect to problems solved and problems being addressed needs to be provided in a future Annual Merit Review (AMR) to help further evaluate accomplishments."
  - Response: we will try to clarify better on research questions and result insights.
- "More ambitious goals using data-driven approaches to calibrate and validate the project team's existing models should also be considered."
  - Response: we have focused more on data-driven approaches, such as the MA3T calibration, charging infrastructure analysis and air taxi external energy impact study.

Project review scores from AMR 2019

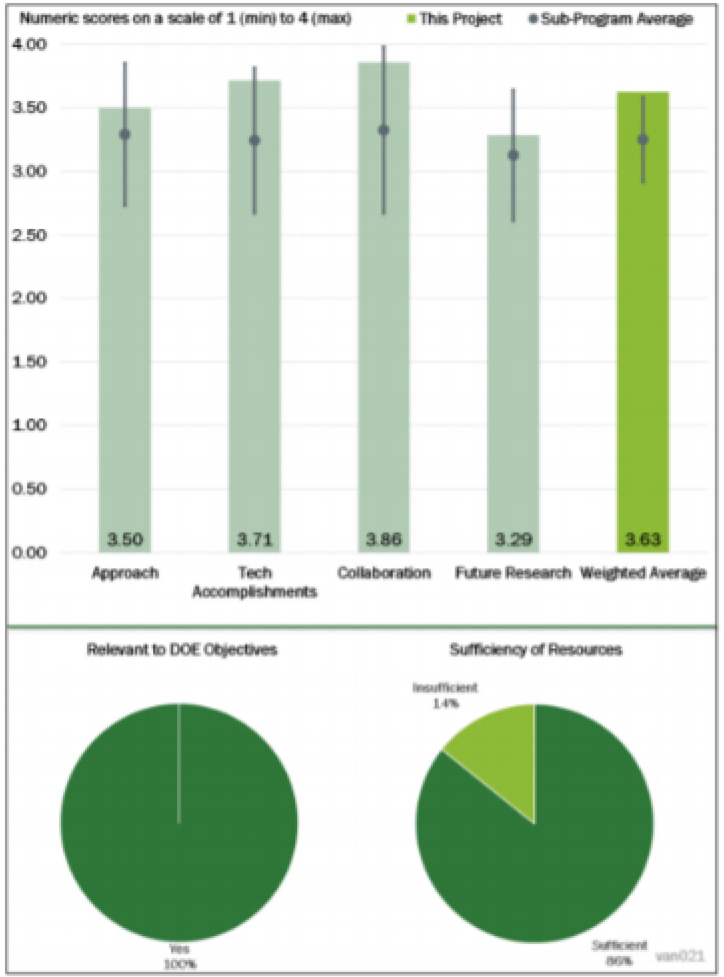
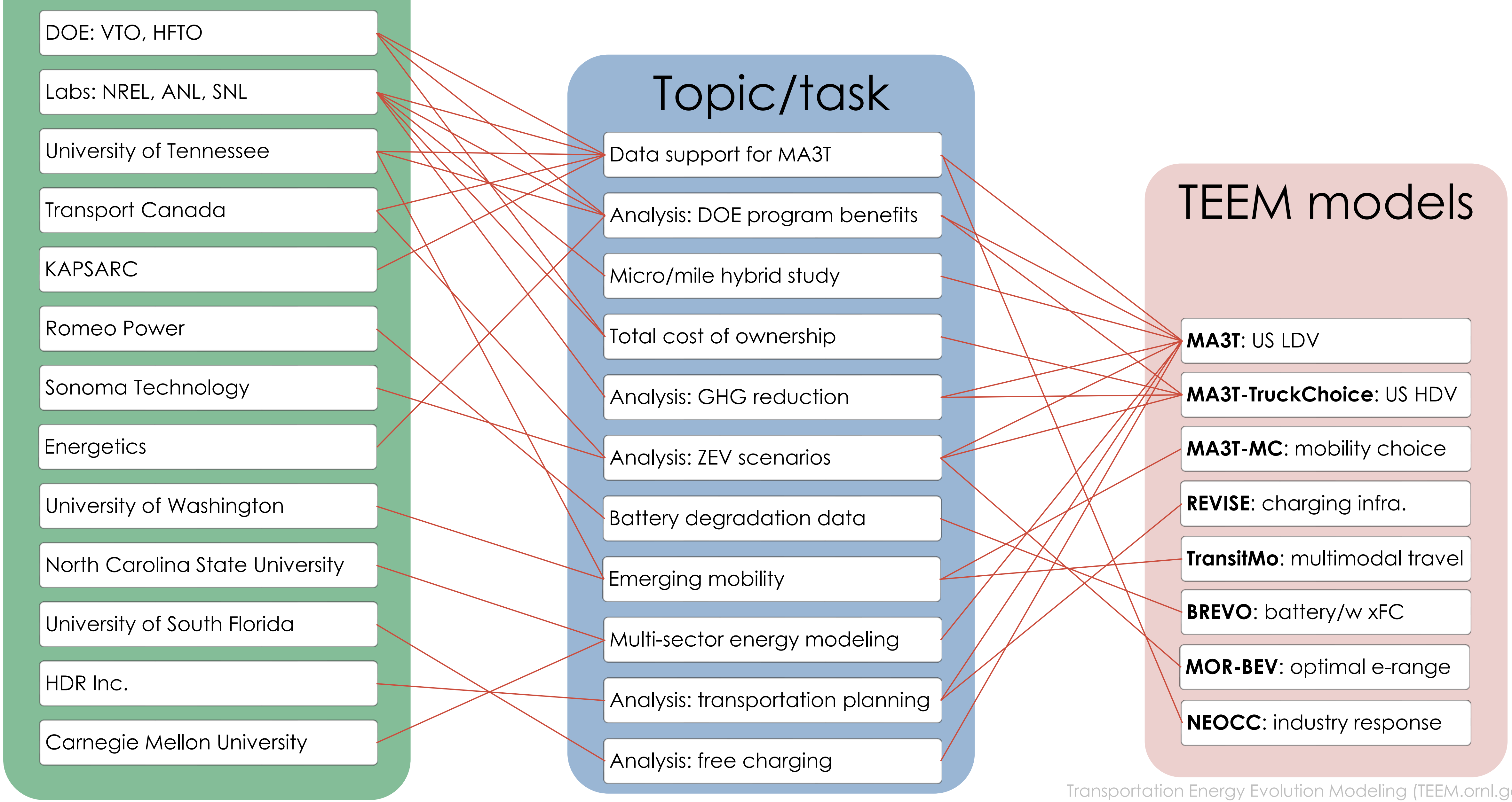


Figure 8-2 – Presentation Number: van021 Presentation Title: Transportation Energy Evolution Modeling (TEEM) Program Principal Investigator: Zhenhong Lin (Oak Ridge National Laboratory)

Collaboration and Coordination



Remaining Challenges/Barriers

- Model the adoption barrier of PHEVs
- Understanding the industry's strategy on BEV vs PHEV
- Data availability for heavy-duty electrification
- Implications of COVID-19 for energy transition

Proposed Future Research

- PHEV vs BEV analysis(Q3 milestone)
- MA3T improvements and new developments(Q4 milestone)
- FY20-21
  - Developing MA3T-Used model to address legacy vehicle issue
  - Analyze impacts and strategies of large-scale deployment of charging infrastructure
  - Simulate employment impact of vehicle electrification
  - Continue development of MA3T-TruckChoice

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

TEEM FY20-21 summary

- **Relevance**
  - Transportation energy transition; VTO mission and new tech portfolio; modeling technology adoption dynamics
- **Milestone** – on track
  - Extreme fast charging analysis
  - Upcoming: PHEV vs BEV; MA3T update
- **Approach**
  - Organized activities by Data, Model, Decision and Impact.
  - Use MA3T, -MC, -TruckChoice, -China, REVISE, BREVO to link relevant assumptions to analysis of impacts
  - Collaborate widely to improve assumptions, logic linkages, and application of the models
- **Accomplishment**
  - A suite of market dynamics models for different technology and region focus
  - Innovative methods and analysis insights
  - Publications: 12 published or accepted since 2020 AMR, 3 under review for journals; 5 working drafts
- **Collaboration**
  - Multiple universities, labs and companies supporting assumptions, model development and model applications
  - TEEM provide technical support to external users and gather feedback

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Vehicle Technologies Office
US Department of Energy

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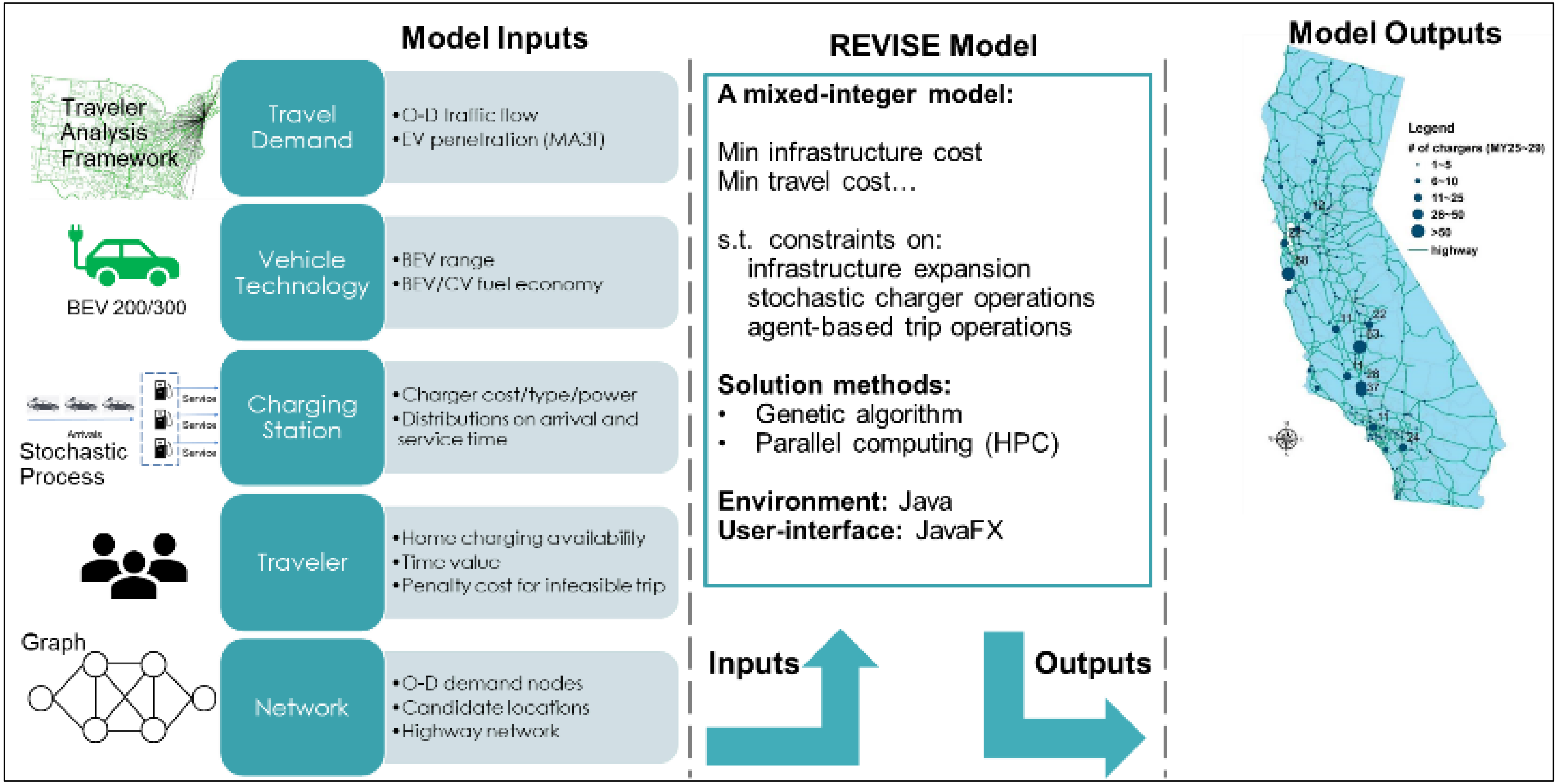
Technical Backup Slides

Regional Electric Vehicle Infrastructure Strategic Evolution (REVISE) Model



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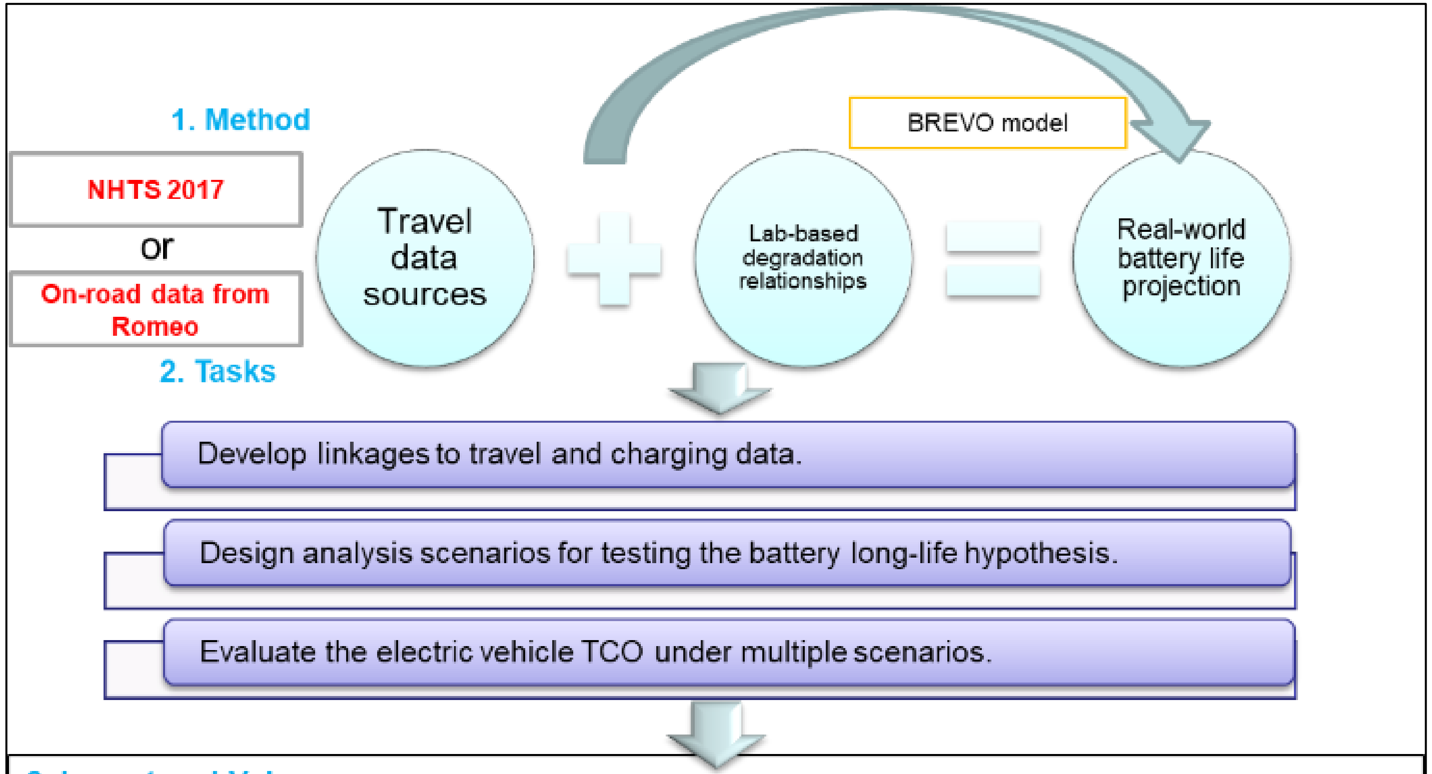
Approaches of additional selected models/studies

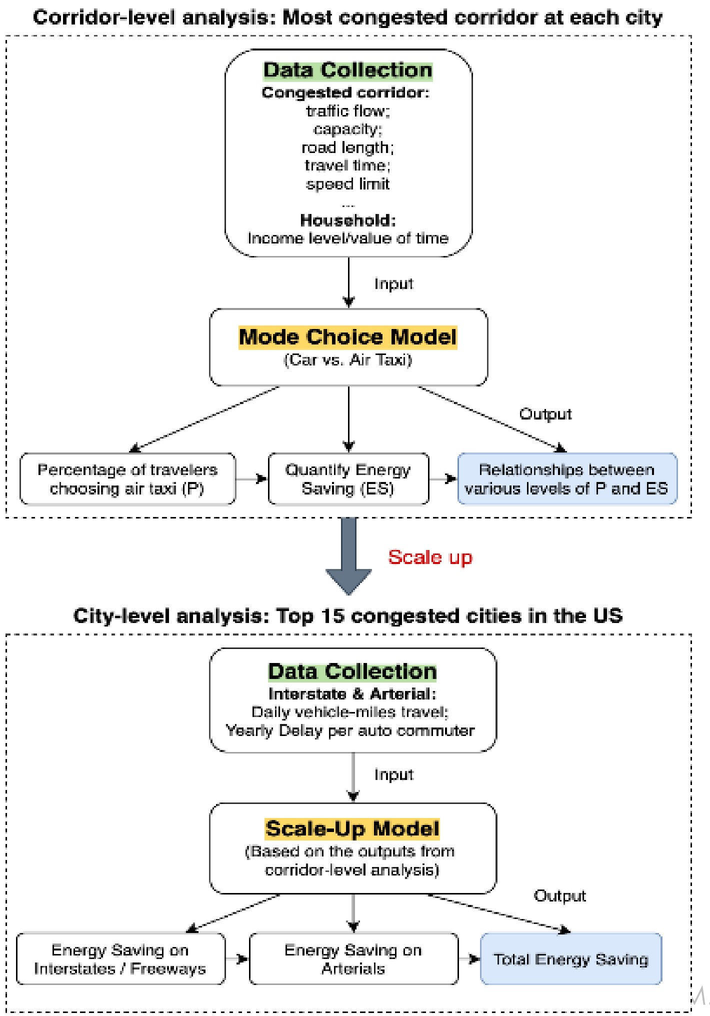
Battery Run-down under Electric Vehicle Operation (BREVO) Model



3. Impact and Value:

1) Inform stakeholders R&D investment and target setting;
2) Inform technology integration in consumer information;
3) BEV manufacturers could provide longer battery warranty;
4) Lead to greater consumer acceptance of BEVs.

Traffic Energy with Air-taxi (TEA) model



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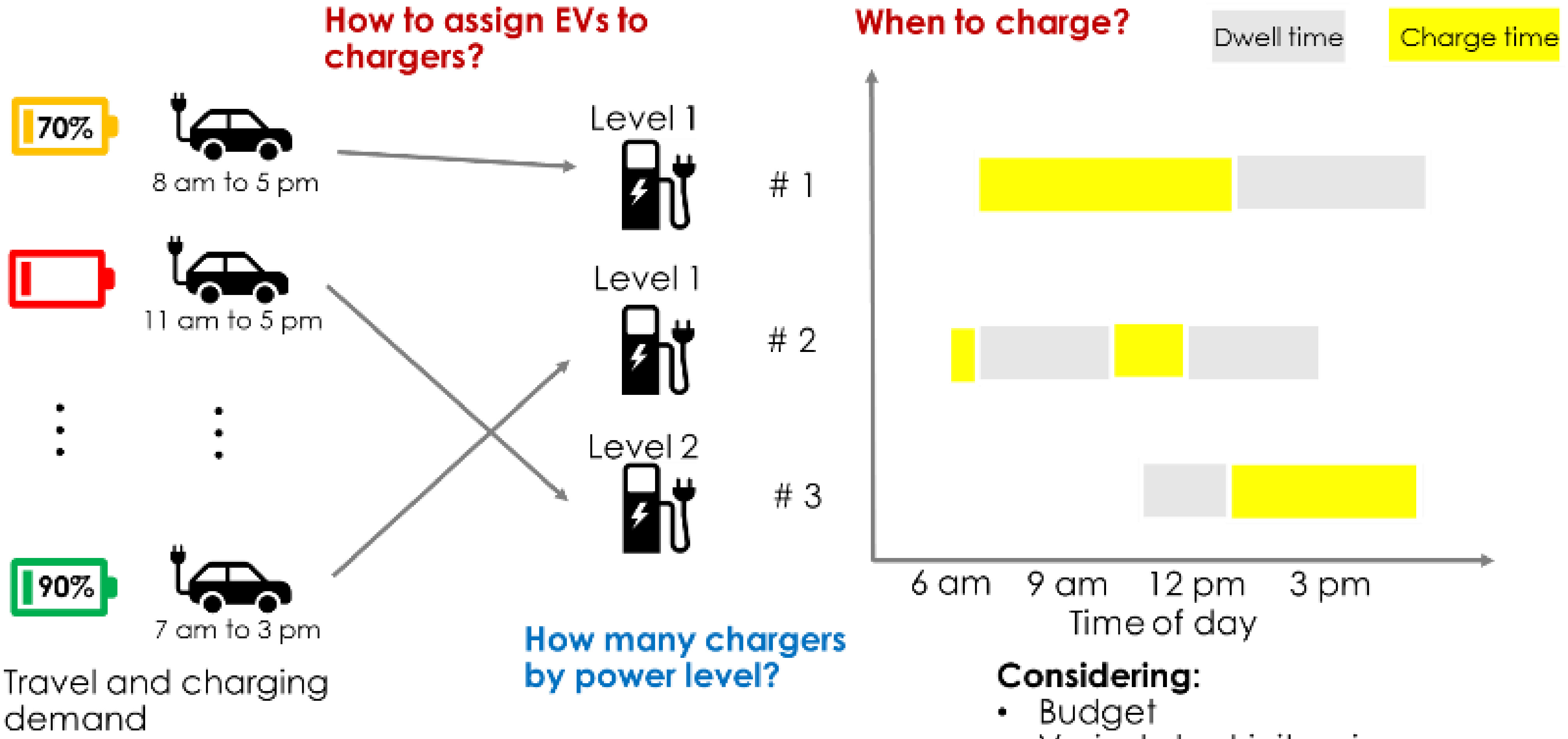
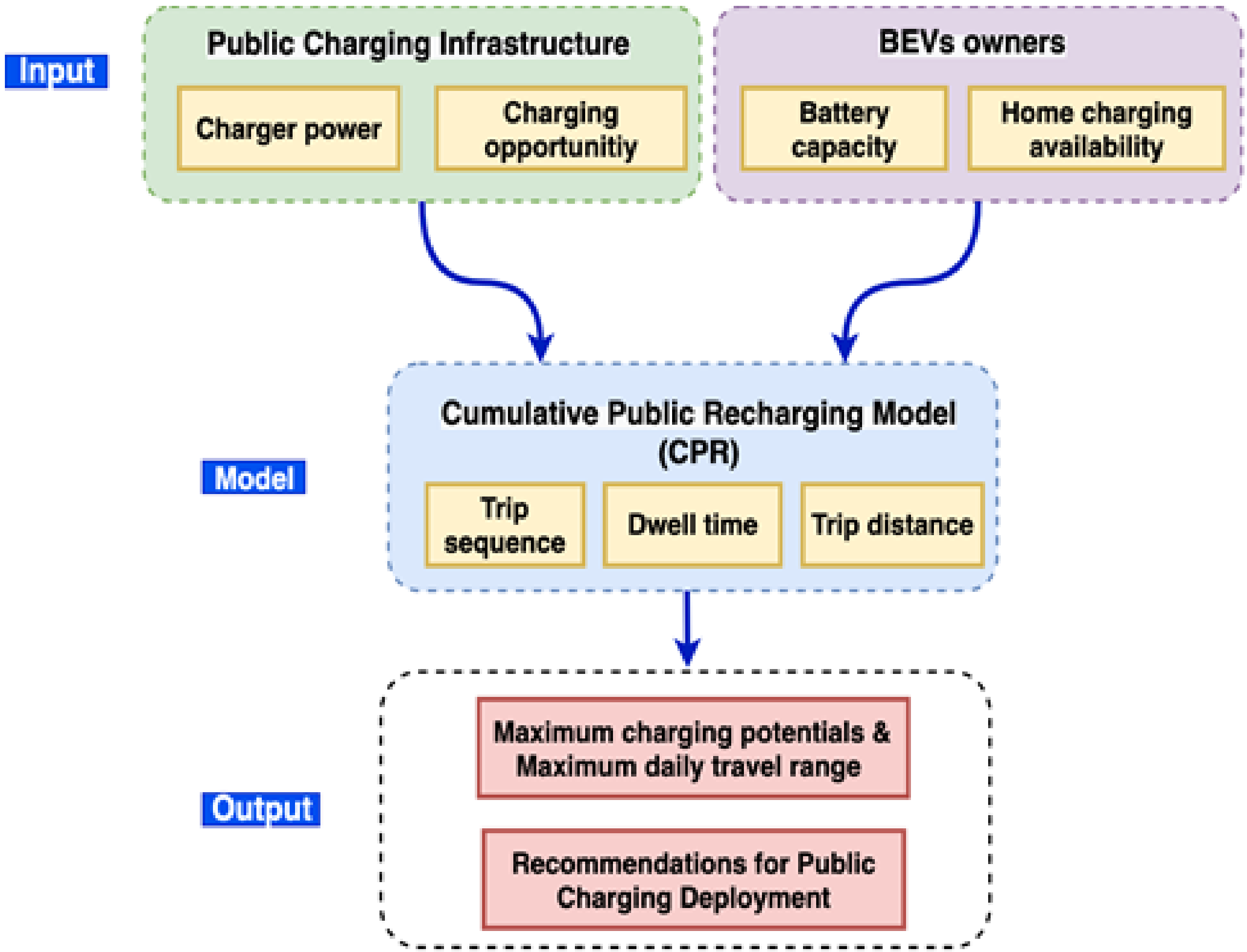
Workplace charging optimization

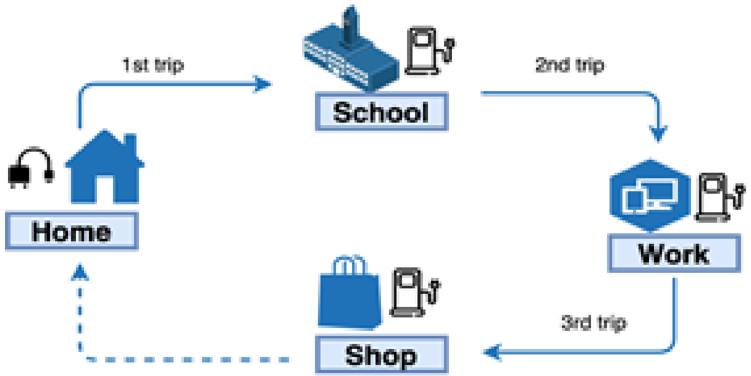


Considering:

- Budget
- Varied electricity price
- Demand charge

Valuing fast charging technologies





FY21 publications: 12 published or accepted since 2020 AMR, 3 under review for journals, 5 working papers

1. Liu, N., Xie, F., Lin, Z., Jin, M.. 2021. Empirical Estimation of Route Length Along U.S. Interstate Highways Based on Great Circle Distance. Transportation Research Record (accepted).
2. Ou, S., Yu, R., Lin, Z., He, X., Bouchard, J., & Przesmitzki, S. (2021). Evaluating China's Passenger Vehicle Market under the Vehicle Policies of 2021–2023. *World Electric Vehicle Journal*, *12*(2), 72.
3. Burnham A, Gohlke D, Rush L, Stephens T, Zhou Y, Delucchi MA, Birky A, Hunter C, Lin Z, Ou S, Xie F. Comprehensive Total Cost of Ownership Quantification for Vehicles with Different Size Classes and Powertrains. Argonne National Lab.(ANL), Argonne, IL (United States); 2021 Apr 1.
4. DeCarolis, J. et al. (including Z. Lin) (2020). Leveraging open-source tools for collaborative macro-energy system modeling efforts. *Joule*, *4*(12), 2523-2526.
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6. Greene, D. L., Ogden, J. M., & Lin, Z. (2020). Challenges in the designing, planning and deployment of hydrogen refueling infrastructure for fuel cell electric vehicles. *eTransportation*, 100086.
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11. Dong, J., Wu, X., Liu, C., Lin, Z., & Hu, L. (2020). The impact of reliable range estimation on battery electric vehicle feasibility. *International Journal of Sustainable Transportation*, *14*(11), 833-842.
12. Ou, S., Gohlke, D., & Lin, Z. (2020). Quantifying the impacts of micro-and mild-hybrid vehicle technologies on fleetwide fuel economy and electrification. *eTransportation*, *4*, 100058.

~ 75 publications co-authored by TEEM members since 2010, available at https://TEEM.ornl.gov